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Identification of Winter Wheat With Landsat MSS Digital Data

by

GORDON C. REICHERT

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

IN

Remote Sensing

Department of Soil Science

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Identification of Winter Wheat With Landsat MSS Digital Data submitted by GORDON C. REICHERT in partial fulfilment of the requirements for the degree of Master of Science in Remote Sensing.

.....

Supervisor

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Date.....March 13, 1985...

God said, Let there be light: and there was light.
And God saw the light, that it was good.....

Genesis 1:3,4

ABSTRACT

Seventy-five percent of Canada's winter wheat is grown in Alberta with 45% of this in the Warner - Foremost region. The objective of this study was to develop and test a model by which the location and areal extent of the winter wheat crop in Southern Alberta may be determined using resource satellite digital data.

A preliminary model was developed and tested using satellite digital data from the fall of 1982 and the spring of 1983. The model was then applied to a second growing season during the fall of 1983 and the spring of 1984.

Two methods of classification accuracy assessment were employed: total areal extent and location analysis. Winter wheat signatures were exchanged between representative test segments with accuracy assessments conducted using the above techniques. Signature extension was then applied to a large geographical area for each year of the study. Post-classification filtering was conducted to demonstrate the effect of this subjective technique on the accuracy assessment.

Average classification results for the 1982-83 and 1983-84 growing seasons estimated the total area within 4% of the ground truthed data. Average location accuracies were within 12% for the former and 18% for the latter.

Multidate classification reduced commission errors for 1982-83 and 1983-84 by 25 and 31%; respectively. However, the percent of winter wheat correctly classified was reduced

by 3% during 1982-83 and 8% during 1983-84. A decrease in the percentage of correctly classified winter wheat was compounded by the multidate registration problem, boundary pixels and the poor spatial resolution of the Landsat MSS system relative to the narrow fields in Southern Alberta. Omission errors resulted from unclassified boundary pixels, a problem compounded by the pattern of relatively narrow fields. Multidate classification of a segment containing cloud, cloud shadow and thin haze neither improved % correctly classified nor reduced % commission error.

During the 1982-83 growing season, location accuracy assessment of single segment signature extension using spring data only, consistently underestimated the recipient segment. Classification of individual test segments using multi-segment signatures of unitemporal and multitemporal data bases resulted in highest percent of winter wheat correctly classified. Generally, omission errors increased proportionally with the percent increase of correctly classified winter wheat pixels.

Post-classification filtering resulted in a higher percent correct classification and a smaller commission error provided small fields of less than three pixels in width were not included.

Signature extension over a large geographical area resulted in a 93 to 94% correct classification of "blind site" winter wheat fields in southern Alberta for the two year study period.

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1. INTRODUCTION

The benefits of crop monitoring through satellite remote sensing have been estimated to be millions of dollars for both the United States (Osterhoudt 1978) and Canada (Clough *et al.* 1974). Increasing competition among grain exporters in recent years and the instability of grain markets have underscored the importance of having accurate information on the supply and demand for grain in both the importing and exporting nations of the world (Glick *et al.* 1983). Current national crop forecasts provided by yield models are generally not available until mid-to-late summer (Garron 1980). For marketing purposes and hopper car allocation, accurate production data are required as early in the growing season as possible. The potential for timely monitoring crops and crop conditions over large geographic areas, both nationally and internationally, is provided by satellite data with repetitive global coverage.

Winter wheat (*Triticum aestavium L.*) may be particularly suited to inventory by satellite due to its relatively unique crop calendar. Winter wheat is a fall seeded cereal requiring primary vegetative growth in the fall to establish sufficient root growth and winter hardiness. During the winter months, winter wheat becomes semi-dormant maintaining low respiratory activity. With increased sunlight, soil temperature and moisture associated with the onset of spring, winter wheat begins its reproductive growth stage. Regeneration occurs from crown

tissue and winter survival is dependent upon the temperature to which this part of the plant is subjected. Should winterkill occur, the estimation of its severity using satellite data requires that individual winter wheat fields be firstly identified early in the spring and subsequently monitored. In normal practice, a survival rate of less than 40% in a field will result in a planting being turned under. Snow cover, however, reduces the chance of winterkill from freezing temperatures (Fowler 1982). Seeding rates, dates and depths, fertilizer rates,types and date of application, previous crop, variety and row spacing influence winter survival.

Winter wheat accounts for approximately 70% of the world wheat trade (The Canadian Wheat Board 1983). Seventy-five percent of Canada's winter wheat is grown in Alberta with 45% of that in the Warner-Foremost region. Although a small portion of the world's total is grown in Canada, the total area of winter wheat in this country is expected to increase.

The objective of this study was to develop and test a model by which the location and extent of winter wheat in southern Alberta may be determined using resource satellite digital data.

2. LITERATURE REVIEW

2.1 Satellites and Crop Inventories

Monitoring agricultural regions to estimate total crop area directly (primary production) and infer grain production by indirect methods, using digital image processing techniques, was not possible in the 1960's as sufficient digital image data were not available (Landgrebe 1981). Major advances have been made since 1960 in instruments, remote sensing devices, equipment and sampling strategies for observing, characterizing and monitoring a target or scene.

Evaluation of crop growth and field crop area from airborne imagery was begun by Agriculture Canada in the mid 1960's. Initially, camera-film systems using colour infrared film were used to discriminate vegetation. In the early 1970's, studies were expanded to include spectral data of crops and soils using a wide range of photographic and electronic measuring systems carried by both aircraft and satellites (Mack and Bowren 1973, Philpotts *et al.* 1974). Temporal scene variations have long been suggested as possible sources of useful information (Steiner 1970). The details of seasonal vegetative change in earth surface cover classes with respect to the crop calendar, are indicators of the class of cover type and easily surveyed using satellite techniques.

The multispectral scanners (MSS) on the Landsat satellite series are capable of collecting data in the visible and infrared portions of the electromagnetic spectrum (0.5 - 12.6 micrometers) (Baumgardner 1982). The energy reflected from a small area on the earth's surface is sensed by the scanning mirrors, then reflected through a system of optics that disperse the energy spectrally. The energy in the visible wavelengths is spread by a quartz prism; dichroic gratings serve as dispersive devices for the infrared energy. The detectors are arranged spatially so that the appropriate detector can sense the wavelength region to which it is sensitive.

The motion of the satellite provides the along-track scan motion; whereas, the line scanner itself develops the across-track scan motion. Thus, a continuous area of the earth's surface can be sensed in several wavelength bands simultaneously. Each Landsat scene provides ground coverage of approximately 185 by 170 kilometers.

The signal from each detector is amplified and processed (passed through a filter and/or digitized) and is then recorded on board the satellite or transmitted by telemetry to a receiving station. The telemetry signals from the satellite are received, amplified and demodulated into their digital formats through a processing system that converts the data into computer compatible tapes (CCT's) suitable for digital computer processing. In the processing of producing the CCT's the ancillary data corresponding to

the particular scene being sensed are merged with the multispectral data. These include the limits of the particular spectral band being recorded, the coordinates of the center of the scene, the time of day and solar elevation at which the data in the scene were acquired, and a variety of special calibration signals which indicate the dynamic range of the data in the scene. The picture element, or pixel, brightness of each band has a numerical value ranging from zero for black (no energy reflected) to 255 for white (maximum energy reflected) within each band.

The first satellite designed specifically to collect data of the earth's surface and resources was the *E*arth *R*esources *T*echnology *S*atellite (ERTS), later named Landsat-1. The launch of Landsat-1 satellite by NASA in July 1972 ushered in a new era in earth observations. Landsat 2 and 3 followed in January 1975 and March 1978; respectively (Table 1). The orbit chosen for the Landsat satellites was the best comprimise in terms of the type of coverage desired, the constraints of the sensor system and the dictates of the laws of orbital mechanics. The type of orbit desired was circular (for near constant resolution and scale), cyclically repetitive (for periodic observation of the same site), and sun-synchronous (for constant illumination). The result was an 18-day repetitive cycle at a nominal altitude of approximately 920 kilometers. After 5 years of successful data acquisition, Landsat 1 was retired from service in January 1978. Deterioration in performance

Table 1. Specifications of the return beam vidicon (RBV) and multispectral scanner (MSS) on Landsat 1, 2 and 3 (modified after Baumgardner 1982).

Landsat	Sensor	Spectral Bands (micrometers)	Description	Spatial Resolution (meters)
1,2	RBV	0.475-0.575	Visible blue, green	80
		0.580-0.680	Visible orange, red	80
		0.690-0.830	Reflected infrared	80
3	RBV	0.505-0.750	Panchromatic	30
1,2,3	MSS	0.5-0.6	Visible green	80
		0.6-0.7	Visible red	80
		0.7-0.8	Reflected infrared	80
		0.8-1.1	Reflected infrared	80
		10.4-12.6	Emitted infrared'	240

' Landsat 3 only

of Landsat 2 sensors in late 1979 led to a shutdown of its data acquisition system after 4 years of service. In 1981, however, Landsat 2 was reactivated after Landsat 3 developed data transmission problems. Landsat 4 was launched in July 1982 and carried a high ground resolution Thematic Mapper (TM) and a multispectral scanner. The Landsat 4 thematic mapper ceased normal operation in February 1983. Landsat 5, launched in March 1984, continues to employ the same four reflective bands of the previous Landsat multi-spectral scanners but adds a Thematic Mapper (Table 2). The TM, a line scanning device, operates over 7 bands of visible and infrared electromagnetic spectrum and has a ground resolution cell size of 30 m for all reflective bands and 120 m for the thermal band. Landsat 4 and 5 have a nominal orbital altitude of approximately 705 km and maintains a 16-day cycle of repetitive coverage.

Often-cited limitations of the Landsat series are its spatial resolution (Table 1 and 2), spectral channels not precisely aligned to known absorption bands and cloud cover.

Many investigators determining the separability of agricultural crops have concentrated on Landsat MSS data. Kumar (1978) evaluated 12 spectral channels of airborne data within the visible to thermal infrared for discriminating agricultural cover crops. Maximum separation of agricultural cover types was obtained by using all 12 channels, however, separability was not significantly better than when 4 spectral bands from the visible, infrared, middle infrared

Table 2. Specifications of the Thematic Mapper of Landsat 4 and 5 (modified after Baumgardner 1982).

Landsat	Sensor	Spectral Bands (micrometers)	Description	Spatial Resolution (meters)
4,5	TM	0.45-0.52	Visible blue	30
		0.52-0.60	Visible green	30
		0.63-0.69	Visible red	30
		0.76-0.90	Reflected infrared	30
		1.55-1.75	Reflected infrared	30
		2.08-2.35	Reflected infrared	30
		10.40-12.50	Emitted infrared	120

and thermal infrared were employed. Landgrebe *et al.* (1977) determined that 6 airborne bands in the visible, near- and middle infrared are the optimum number of bands to use. An increase in the number of channels used in a classification algorithm, however, requires a disproportionate increase in computer time.

Potential applications of Thematic Mapper (TM) data for agricultural purposes have been demonstrated through simulations using airborne data (Ahern *et al.* 1980, Thompson *et al.* 1983, Crist and Cicone 1984). Acquisition of TM data by Landsat 4 ceased in February 1983 with failure of the spacecraft's transmission electronics (NOAA 1983). Activities resumed on a limited basis when a link was re-established via the Tracking and Data Relay Satellite System (TDRSS) later that summer. One Landsat 4 TM acquisition with less than 20% cloud cover and a solar altitude greater than 20° was available for southern Alberta. The thematic mapper aboard Landsat 5 remained in a research and development mode until January, 1985. Therefore MSS data had to be used for this study.

In 1970, an event of considerable importance to remote sensing occurred. The world's primary corn producing region was invaded by a fast-spreading fungus. A new strain of fungus (*Helminthosporium Maydis*) spread from southern U.S. corn producing regions up the Mississippi River Valley and through the seven-state U.S. Corn Belt area. Little was

known of the characteristics of the disease other than its drastic reduction of corn production. The corn production predicted in 1970 was 4.82 billion bushels, but the blight ruined 15% of the crop (MacDonald 1983).

During 1971, a "corn blight watch" experiment for the seven-state Corn Belt region was implemented (MacDonald *et al.* 1972). The "watch" was the first test of remote sensing for monitoring such a large region frequently throughout a complete season. In addition, it was the first attempt to shift from a research mode to an operational state using the developed analysis techniques. The results established the validity of the use of both small scale multi-spectral photography with manual analysis and electronic data with machine processing. However, the objective machine processing of electronic MSS data proved to be more reliable (MacDonald *et al.* 1972). It was concluded that major crop types in field sizes common to the corn belt could be determined with data collected at periodic intervals through the season. This provided considerable impetus for future multi-temporal research with multispectral data.

In 1974, the Large Area Crop Inventory Experiment (LACIE), a joint effort of National Oceanic and Atmospheric Administration (NOAA), the United States Department of Agriculture (USDA) and National Aeronautics and Space Administration (NASA), began to apply satellite remote sensing technology on an experimental basis to forecast harvests in important wheat production areas of the world.

The LACIE inventory system was designed to achieve monthly at-harvest production estimates that would converge to within 10% of the true estimates at the national level with a confidence of 90 percent. Area estimates were made from classifications of Landsat MSS data. Yield was estimated for broad geographical regions using statistical regression models developed from historical weather and wheat yield data. Completed in 1978, the LACIE program demonstrated that remote sensing from earth orbiting satellites can provide accurate, timely information on foreign commodity production, and that this information is more accurate than data generated by existing data-collection methods (Colwell 1983).

Accurate crop-production forecasts require accurate forecasts of the total crop area for harvest, its geographic distribution and the associated crop yield as determined by local conditions. Total crop area and yield are sufficiently variable from year to year to require periodic monitoring. These variations are created by slowly changing factors, such as irrigation, fertilizers and climate and by rapidly changing factors such as weather, market price and government policy. During the first half of the crop year, total crop area information has traditionally played a dominant role in market price because early in the season, total crop area is more predictable than is crop yield.

Jensen *et al.* (1978) compared the utility of multi-date crop classification using microdensitometer scanned color

infrared, high-altitude photography and Landsat digital data for a 140 km² geographical area. Landsat digital data were found to be superior, particularly when vignetting in the high altitude photographic data set caused serious signature extension problems. Over the last 15 years, studies have repeatedly shown that certain groups of crops, types of crop losses, and crop growing conditions could be readily determined and their areal distribution in a crop district, region or province, accurately measured using Landsat data (Mack 1980). Total area of corn and canola were early successes and methodologies or models for the use of satellite data continue to be refined (Plourde 1983). Weigand *et al.* (1973), Rouse *et al.* (1973) and Kanemasu (1975) demonstrated, using both theoretical and emperical evidence, that spectral signatures in the Landsat wavelength bands were related to the amounts of crop vegetation or primary production. Analagous use of Landsat data to estimate grain yield (secondary production) was conceived to be possible by inferring grain production from vegetative production (direct methods), or by using estimates of vegetative variables as input to agrometeorological models (indirect methods).

A critical issue in the direct spectral-yield approach was the reliability of relationships between grain production and the corresponding "green" vegetation. The forecast accuracy of even the perfect yield model is limited by uncertainty about future events. Agronomists have

traditionally been aware of the difficulty in predicting yield from crop appearance, especially in deceptive cases where weather events affect pollination (Stuff and Barnett 1979). Most direct methods proposed use observations at or prior to heading without a comprehensive assessment of yield variability caused by post heading factors.

Historically, Statistics Canada has used annual mail census surveys as the primary input into crop estimations. Probability enumeration surveys were later introduced, eliminating varying response rates and possible non-representativeness of respondents.

Conventional current forecasts of crop areas and production are inaccurate and too late to be really useful (Bauer *et al*. 1978, Duggin *et al*. 1978). The advantage of using LANDSAT data for agricultural purposes is that each scene provides coverage of a wide geographic area, multiple spectral bands of data are available in digital format for data processing while image products allow evaluation of digital data before processing. The spatial and temporal nature of the Landsat based data provides whole-field estimates of crop cover throughout the season and surveys more fields than subjective field estimates. Non-uniformity within fields is accounted for, whether it is due to disease, insects, fertility, drought or cropping practices.

Ryerson *et al*. (1981) demonstrated that satellite imagery combined with more traditional crop area estimation procedures can lower respondent burden, produce timely crop

distribution maps and produce reliable estimates for subregions. Hanuschak *et al.* (1979a,b) combined Landsat data and ground data to produce substantially more precise results over state, multi-county and individual county levels, than those made from ground data alone.

Researchers have demonstrated that multitemporal versus unitemporal Landsat data can be used to classify winter wheat with increased accuracy (Beach and Dawbin 1981, Mergerson 1981). Hlavka *et al.* (1979) emphasized the optimum choice of imaging times for winter wheat would be the late fall and early spring with the best single observation time being the spring. Although use of multi-temporal data requires a more complex data-processing system (registration, increased data base size), the increased complexity may be justified by increased performance. Virtually all crop identification techniques, whether unitemporal or multitemporal, rely on the ability to detect consistent characteristic spectral data of a particular crop. Consequently, these techniques are likely to be substantially and adversely affected by differences in the spectral characteristics of a crop resulting from changes in cultural or environmental conditions. Crist (1982) and Daughtry *et al.* (1980) concluded that variations in cropping practices and/or field conditions which are typically seen over relatively small regions (fertilizer(s), planting date, plant population, variety, row spacing, disease and soil moisture) can significantly affect the reflectance values of

the crop.

An understanding of the winter wheat crop calendar is necessary to determine the optimum imaging dates and influencing factors affecting winter wheat identification by satellite imagery in southern Alberta.

2.2 Crop Calendar

As a fall seeded crop winter wheat makes more efficient use of early spring moisture than spring seeded cereals and prevents wind and water erosion in the fall and spring. In addition, winter wheat competes better with weeds than spring seeded cereals (Fowler, 1982).

2.2.1 Seeding

Norstar winter wheat is predominantly grown in southern Alberta as a result of its ability to withstand winterkill. Less hardy varieties such as Winalta, Kharkov and Sundance are still being grown as they produce satisfactory yields.

Soil moisture is a major consideration in planting winter wheat. An adequate supply of soil moisture is essential for root development which helps winter wheat survive the winter. Recommended seeding dates are from the third week of August to the second week of September (Fowler, 1982). Seeding rates of 75 kg/ha at a depth of 2.5 to 4 cm into firm, moist packed soil are recommended for optimum germination. Deeper seeding often results in delayed emergence and weak plants which are subject to winterkill.

Ideally, winter wheat should grow to the 3 - leaf stage in the fall before dormancy sets in. If seeded too early, the extra fall growth will leave a disease-harbouring carpet of dead crop tissue in the spring.

Hoe-drills are used for seeding because they have the advantage over disc-drills of seeding into the moist subsurface soil even when the surface is dry and firm. Growers in Southern Alberta usually seed winter wheat into summerfallow allowing good fall weed control. Tall, dense stubble stands may trap more snow in the winter and provide extra springmelt water. However, they may also result in a slower snowmelt and cooler soil temperatures in the spring. These factors, combined with increased shading, may result in slower spring plant growth. If seeded into stubble, yields may be reduced as the plants become susceptible to root rot, streak mosaic and/or phytotoxins produced during the decomposition of crop residues.

Phosphate fertilizers are placed with the seed to enhance healthy, vigorous root development in the fall to maintain an adequate stand throughout the winter months. Nitrogen fertilizers are applied in the spring to aid vegetative growth and seed filling.

2.2.2 Winterkill

Winter cereals regenerate from crown tissue (Young and Rourke, 1982). Therefore the temperature to which this part of the plant is subjected is a critical factor in winter

survival. The highest degree of cold hardiness is usually attained just before or at freeze-up and from then until spring it is reduced. Death of the crown tissue will result if the temperature falls below its minimum survival temperature at any time during the winter. Five continuous days of -16 to -20°C, 2.5 cm below the surface can kill the growing point (Nelson and Olien, 1966). Fifteen to thirty cm of snow will prevent this, even in -40°C weather since snow is an efficient insulator. Although snow cover may reduce the chance of winterkill from severe temperatures it may increase the probability of winter damage by snow mould (Smith, 1975).

Although there might be a yield reduction of winter wheat at less than 60 - 65% survival, (Fowler *et al.*, 1976; Young and Rourke, 1982) a survival rate of greater than or equal to 40% is considered adequate to provide a reasonably good stand, provided plants are properly spaced. Increased tillering compensates for much of the loss of the stand (Alessi and Power, 1971). However, if the survival rate is less than about 40% the planting is generally turned under and spring grains are seeded. If spotty areas of winterkill occur in a field and the rest of the winter wheat is a good stand, the dead winter wheat area may be reseeded to spring wheat.

2.2.3 Harvest

Harvesting of winter wheat usually occurs 2 weeks prior to that of spring wheat spreading the work load throughout the growing season. Winter wheat outyields spring wheat by 10-20% (Young and Rourke, 1982). Exposure to damp, warm weather in August can result in rapid deterioration of the crop. Producers have attempted to reduce the risk of sprouting by straight combining.

2.2.4 Significance to Remote Sensing

A major problem encountered in the use of satellite data for crop inventories is the potential for spectral confusion between the crop of interest and other crops. However winter wheat has a relatively unique crop calendar, being the dominant fall seeded crop in Southern Alberta (Figure 1). This crop calendar should provide for the discrimination of winter wheat from other crops. As a fall-seeded crop, winter wheat fields should be characterized by green vegetation much later in the fall than other crops which would be harvested in the September-October period. Therefore winter wheat fields should be identifiable on late October images as those which have some green vegetative cover. Fall reflectance values for the infrared bands (6 and 7) range from approximately 85-120 while the reflectance values for visible bands (4 and 5) range from approximately 95-160. It should be recognized however that this crop generally developes to only the

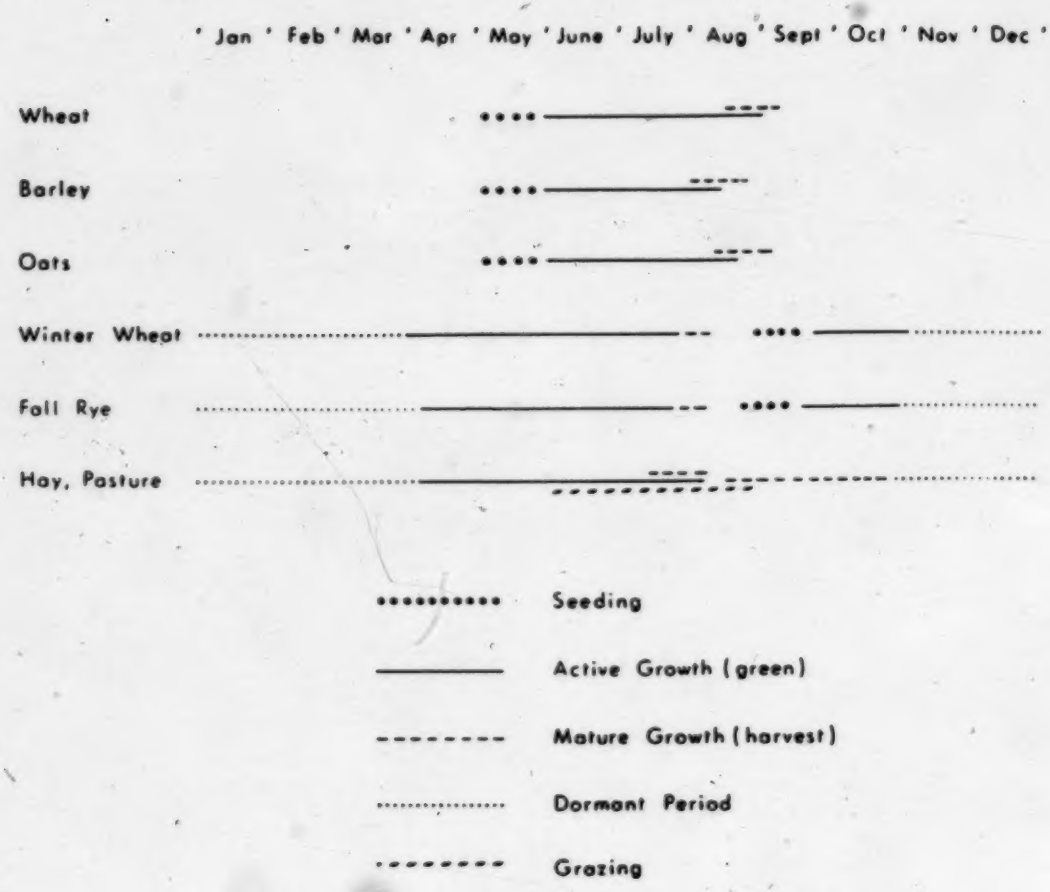

Figure 1. Crop calendar and developmental pattern of winter wheat relative to other crops in the test segments (modified after Atkinson et al. 1975).

3-leaf stage before snowfall and therefore, would not attain 100% ground cover by green vegetation. It is estimated that a crop at the 3-leaf stage of growth would provide approximately 15 to 20% ground cover.

In the spring, winter wheat fields should attain a higher degree of ground cover by green vegetation, earlier than spring seeded crops. Thus the former should be identifiable on early to mid-May images. Spring reflectance values for band 6 and 7 range from approximately 140-255 while the reflectance values for bands 4 and 5 range from approximately 70-115. Confusion with winter wheat and other land cover types is possible. In some areas fall seeded rye may follow a similar crop calendar to that of winter wheat. There is also potential confusion between winter wheat and perennial forage crops, especially in the spring. In the late fall however, forages would be expected to posses a higher percent ground cover by green vegetation than winter wheat.

2.3 Signature Extension

Signature extension reduces the total amount of analyst work required to classify a large geographical area by utilizing crop signatures from training areas developed within relatively small, ground truthed segments. Signature extension accomplishes this by increasing the spatial-temporal range over which a set of training statistics can be used, without a loss of recognition

accuracy. A considerable effort has been made to develop algorithms for signature extension (Lambeke and Rice 1976, Heydorn *et al.* 1978, Kauth and Richardson 1978, Minter 1978). For some test sites and associated imagery it has been reported possible to extend training statistics over 1200 km² without significant deterioration in classification (Goldberg *et al.* 1975). Bauer *et al.* (1978), Mosher *et al.* (1978), Ryerson *et al.* (1979) and Ryerson *et al.* (1981) have successfully used signature extension for the classification of crops over large geographical areas.

Winter wheat in the fall image, should be at a terminal growth stage prior to overwintering and thus present maximum ground cover of actively growing vegetation, reflecting high in the infrared region (band 6 and 7) of the electromagnetic spectrum and low in the visible (band 4 and 5). Similarly, early spring images contain a higher degree of ground cover by green vegetation for winter wheat than spring seeded crops.

A winter wheat area estimate for a region is made by totaling estimates for subregions. Winter wheat area estimates are made by extracting from a segment training data for winter wheat and then using the statistics for these training data to classify the segment pixel by pixel. This local training and classification procedure requires that training data in each segment be labelled by an analyst interpreter.

2.4 Cloud Cover

A difficulty, especially in multitemporal analysis of satellite data, arises as a result of the cloud cover problem. One cannot predict, for a given observation time, which points on the surface may be obscured by cloud. Petcherych *et al.* (1983), after summarizing 28 years of cloud data and assuming that a scene must have less than 21% cloud cover to be useable, concluded that for Calgary Alberta this condition will exist 33% of the time. Hanuschak (1976), Mitchell and Chen (1976) and Nack (1977) used techniques to correct for thin haze, cloud and cloud shadow over the image, requiring time consuming recalculations of spectral values. Michell and Chen (1976), concluded that insufficient Landsat data has been processed to arrive at conclusive results as to the utility of such techniques. Ryerson *et al.* (1981) used an alternate method of calculating crop area under clouds, using the percent crop in areas similar to those obscured by cloud as representative of the crops under the cloud, cloud shadow and associated haze.

3. MATERIALS AND METHODS

Determining the extent and location of winter wheat imposes certain constraints when using Landsat digital data. Ground verification of winter wheat fields and factors influencing winter wheat reflectance of the electromagnetic spectrum within a representative growing area were required in order to develop a working model and apply it. Landsat digital data augmented with field summary data and oblique small format color photographs were analyzed using a compatible computing system and associated software to obtain the desired goal.

3.1 Segment Sites

Preliminary calculations using The Canadian Wheat Board and Alberta Agriculture, Economic Services, Statistics Branch data revealed that approximately 85% of Alberta's winter wheat is grown in southern Alberta census divisions 1, 2 and 3. southern Alberta includes that portion of the province south of Lethbridge to the Canada-U.S. border and from Raymond on the west to Foremost on the east. Over an eight year span, 1976-82, a 45% average of the seeded area was in the Warner-Foremost region (Figure 2).

During the fall of 1982, segment sites at Warner, Skiff and Foremost were selected from within the major winter wheat growing area of southern Alberta. In the fall of 1983, the Skiff test segment was replaced by a test segment at Taber to include irrigated areas in the study.

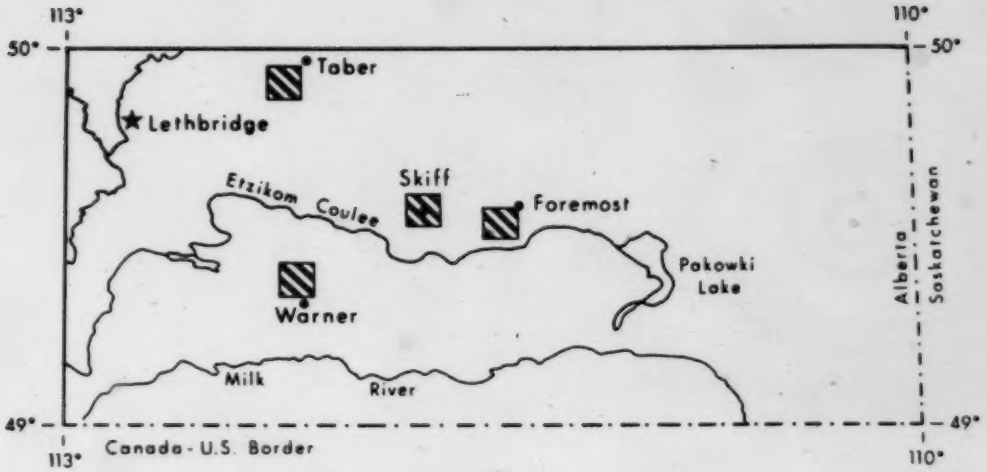

Figure 2. Sketch map of southern Alberta indicating the location of the test segments.

The detailed winter wheat ground data collected for each segment plus segment maps are included in the Appendix.

General field patterns for Warner, Skiff and Foremost segments were typical of the dryland area of western Canada. Field lengths were in increments of 0.4 km while field widths varied with individual producers. Fields were generally oriented in a north-south direction to reduce the potential for soil erosion by the prevailing westerly winds. The Taber segment contained fields representative of dryland and irrigation management practices. Winter wheat fields within the segments were not irrigated. Within the Taber segment spring cereals, special crops and forages were grown under irrigation.

Warner Segment (Plate 1)

The Warner segment is a square, 36 section area northwest of the Warner townsite. The elevation of the segment varies from 968 m in the northeast corner to 1037 m a.s.l. in the southwest. The soils in this area are predominantly Brown Chernozemic developed on medium to moderately fine textured, moderately calcareous till, with Gleysolic and Regosolic soils along Middle Coulee which runs through the centre of the segment.

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Images en couleur

Plate 1. The Warner test segment: Top Left - Color infrared composite, Fall 1982; Top Right - Color infrared composite, Spring 1983; Bottom - Color infrared composite, Spring 1984.

Skiff Segment (Plate 2)

The Skiff segment is located north of Warner surrounding the town of Skiff. The winter wheat segment includes an area of 36 sections (6 east-west, 6 north-south). The elevation throughout this segment is approximately 915 m a.s.l. and the landscape is characterized by gently undulating topography with Brown Chernozemic soils developed on moderately calcareous till material.

Foremost Segment (Plate 3)

This segment site covers an area of 35 sections (7 east-west, 5 north-south) immediately southwest of the Foremost townsite. Topography within the segment varies from gently sloping to gently undulating to undulating on a transect from the north-east corner to the south-west. Elevation changes from 891 m in the northeast to 931 m a.s.l. in the southwest corner. The soils in this segment are Brown Chernozemic developed on moderately calcareous till with minor inclusions of Brown Solonetz.

Taber Segment (Plate 4)

The Taber segment covers a 6 by 6 section area southwest of the Taber townsite. Elevation changes from approximately 914 m at the southwest corner to 838 m at the northwest corner of the test segment. The topography is gently sloping and the Brown Chernozemic soils have

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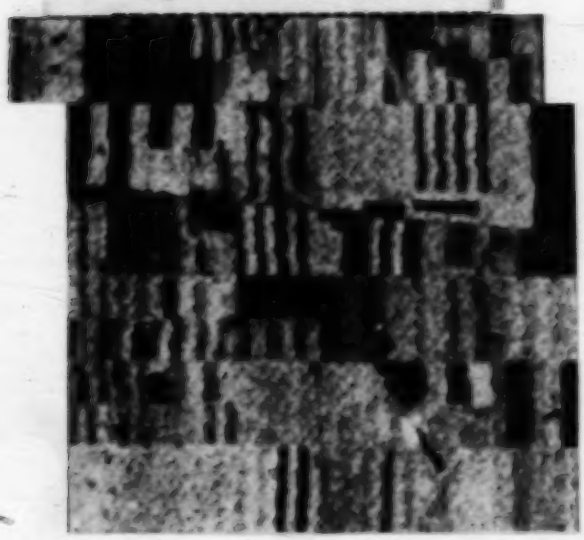

Plate 2. The Skiff test segment: Color infrared composite, Spring 1983.

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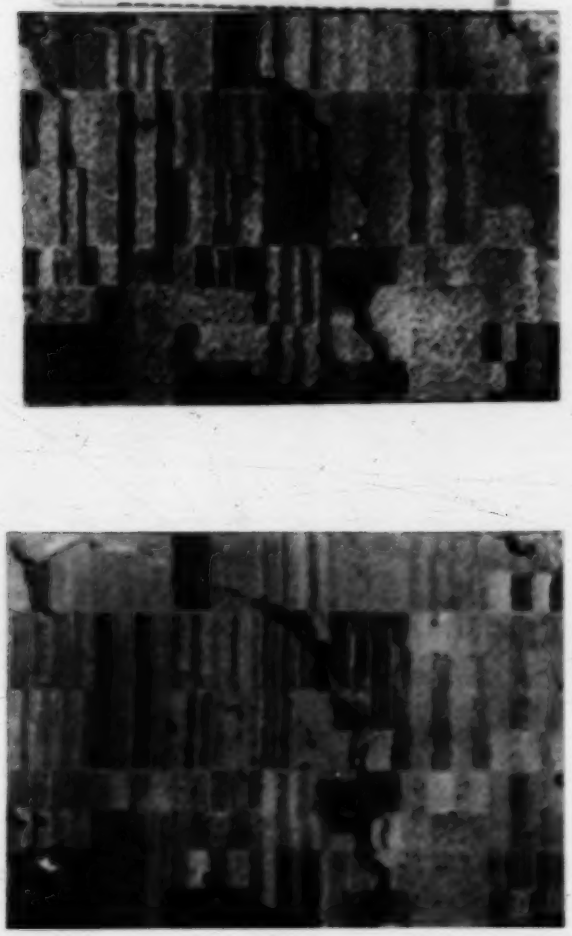

Plate 3. The Foremost test segment: Top - Color infrared composite, Spring 1983; Bottom - Color infrared composite, Spring 1984.

COLOURED PICTURES
Images en couleur

Plate 4. The Taber test segment: Top - Color infrared composite, Fall 1983; Bottom - Color infrared composite, Spring 1984.

developed on till, sorted till and fluvial lacustrine over till with minor inclusions of Brown Solonetz.

3.2 Data Acquisition

3.2.1 Field Data

Field data were acquired for all fields within each test segment. Field size, dates and rates of seeding, crop cultivar and type, date and rate of fertilizer applied and any unusual aspects (such as weeds, drought etc.) were collected through farmer interviews and direct observations. Estimates of percent ground cover, plant height, and comments on crop condition were acquired in the fall and spring of each observation year. Oblique small format color photographs of each test segment were taken from a light aircraft at approximately 1200 m a.g.l. in the spring to augment the ground/field data.

Legal land descriptions of "blind site" winter wheat fields were recorded by District Agriculturalists (DA's) while working in the areas of the test segments for both observation years. The legal descriptions were not made known to the author until the final classification had been completed.

In addition to the DA's reports in the second year of the study, a ground survey was completed after the classification results were available. Over 600 winter wheat

fields of all sizes were observed on the ground and cross-referenced to 1:50,000 UTM and computer plotted winter wheat maps of the same scale and UTM grid.

3.2.2 Satellite Data

1982 - 1983

A May 28, 1983, Landsat 4 image (# 40316-17472) for southern Alberta was acquired from the Prince Albert satellite receiving station as the primary data source. This image provided cloud-free coverage of Warner, Skiff and Foremost segments. A fall image from 1982 was desireable to augment the spring satellite data. The only available cloud-free image provided coverage of the Warner segment and portions of the province to the west. This Landsat 3 image, October 5, 1982 (# 31675-17492) and the spring image were acquired as system corrected computer compatible tapes. No cloud-free 1982 fall imagery could be acquired for the Skiff and Foremost segments.

1983 - 1984

During the second year of operation an October 3, 1983, Landsat 4 image (# 40444-17473) and a May 22, 1984, Landsat 5 image (# 50082-17454) were acquired, the latter being the primary data source. The fall image contained minor cloud and haze over the Foremost test segment while the Taber test segment was not affected. No cloud-free 1983 fall image could be acquired for the Warner segment. All three segments

were clear, cloud free on the 1984 spring image.

3.3 Digital Image Analysis

The image analysis procedures followed are illustrated in the flow chart (Figure 3). Image processing was accomplished using a DIPIX System Ltd. Airies II image analysis system in the Department of Soil Science, University of Alberta.

3.3.1 Preclassification processing

One quarter of each May Landsat scene, containing the test segments, was geometrically corrected and registered to the UTM coordinate system. The fall image was then registered to the spring image for each crop year. To geometrically correct a multispectral scanner Landsat image, ground control points (GCP's) are necessary because of the inaccuracy of the satellite's attitude and altitude measurements. If the attitude and altitude are assumed to be described by certain polynomials of time, the corresponding coefficients can be estimated from the set of GCP's, and their estimated error propogated to obtain an average registration error over the whole image as a function of the GCP's coordinates. Each image was geometrically corrected using 35 uniformly distributed GCP's and a first order affine transfirmation (Dipix 1982). Detectable and recognizable features whose geographic positions are known and assumed they can be located to within 1/4 pixel accuracy

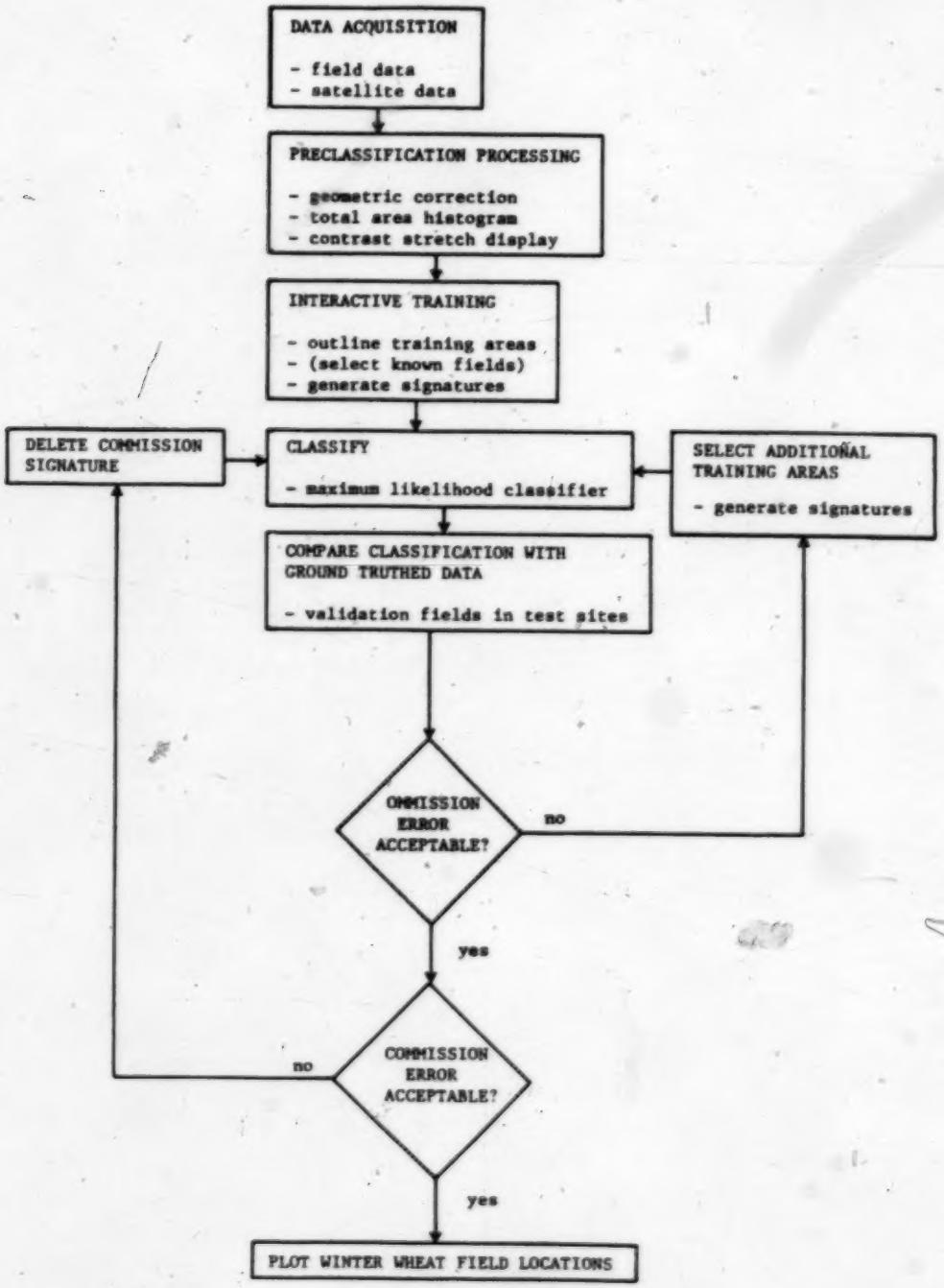

Figure 3. Methodology flow chart for the estimation of total areal extent and location of winter wheat in southern Alberta.

or better, were selected as GCP's. The best GCP's in manual selection were man made features; road intersections and dams. Orti (1981) concluded that the best registration results were obtained when at least 25 GCP's were uniformly distributed over the entire Landsat scene since the registration error increases dramatically outside the GCP's. Accurate UTM coordinate registration with the Landsat images allowed a residual error of less than 1/2 pixel. The images were resampled by cubic convolution to a pixel size of 50 meters. Cubic convolution calculates pixels which are a weighted average of the surrounding pixel values (Bernstein and Ferneyhough 1975).

Less visual confusion between winter wheat and perennial forage crops resulted when contrast stretch data were displayed on the color monitor. Enhanced contrast between and within winter wheat fields also allowed for the visual identification of various crop conditions for inclusion in different training areas.

3.3.2 Signature generation

Winter wheat was the only cover class of interest, therefore, the generation of signatures for all other cover types was considered unnecessary. This reduced the classification to a two class problem : winter wheat versus all other cover types. Each segment was considered separately as farm management practices and the proportion of roughland and forage in each segment were different

(Table 3).

Fields and portions of fields representative of excellent, good and poor stands of winter wheat in May were selected as training areas. These were used to generate signatures, based on Landsat MSS bands 4,5,6 and 7, for all segments. In addition, signatures were generated for the Warner segment (1982-83) and Taber and Foremost (1983-1984) using MSS bands 5 and 7 from each date. Band selection was based on the high positive correlation between bands 4 and 5 and between bands 6 and 7 of each date (Table 4). Light cloud and haze, during the 1983-84 growing season, presented a problem for classification using multitemporal data in the Foremost segment. Winter wheat signatures were generated under thin cloud and haze using the same fields for training areas used in the spring classification.

An important consideration in developing signatures for classification is the size of the training area used. Hlavka *et al.*(1979) and Mergerson (1981) determined that 2.5 and 3 % of the ground truth winter wheat is an adequate sample size for training. Guindon *et al.* (1984) used minimum training areas of 300 pixels with an additional 300 pixels for accuracy assessment. Perry and Hallum (1979) concluded that no recommendation for the optimal sampling size unit can be made until a model for the function of the sampling unit size is developed. Training area sizes of the ground truth data used for classification varied between test segments (Table 5). These percentages were necessary to

Table 3. Percentage of each test segment containing winter wheat and pasture and roughland.

	Winter Wheat	Pasture & Roughland
1982 - 83		
Warner	13	27
Skiff	12	10
Foremost	12	15
1983 - 84		
Warner	13	27
Foremost	17	12
Taber	8	6

Table 4. Correlation matix of spectral bands from spring and fall data for the Foremost and Taber test segments.

Foremost Spring 1984			
	Band 7	Band 6	Band 5
Band 6	0.924		
Band 5	-0.640	-0.365	
Band 4	-0.585	-0.305	0.962

Foremost Fall 1983			
	Band 7	Band 6	Band 5
Band 6	0.931		
Band 5	0.612	0.811	
Band 4	0.596	0.772	0.946

Taber Spring 1984			
	Band 7	Band 6	Band 5
Band 6	0.929		
Band 5	-0.422	-0.124	
Band 4	-0.300	0.004	0.941

Taber Fall 1983			
	Band 7	Band 6	Band 5
Band 6	0.921		
Band 5	0.713	0.824	
Band 4	0.664	0.801	0.934

Table 5. Percentage of winter wheat in each test segment used as training areas for classification.

	Test Segment	Percent
1982 - 83		
	Warner	11
	Skiff	9
	Foremost	28
1983 - 84		
	Warner	17
	Foremost	15
	Taber	27

cover the range in winter wheat variability observed in the fields.

3.3.3 Classification

An initial classification was based on a comparison of individual pixels to signatures generated using a Maximum Likelihood decision rule. The resulting themes left many pixels around field boundaries unclassified. Boundary pixels presented a special problem, as they represented portions of different fields. Their values were a function of the amount of each field within the pixel and the relative reflectance of each cover type as a whole. Colwell (1983) described an experiment conducted in 1969 that classified green vegetation versus bare soil. A 95% accuracy was achieved during the growing season with virtually all of the errors attributed to boundary pixel allocation. Frequently, winter wheat fields may be long and narrow and separate signatures containing boundary pixels are required (Mack *et al*. 1979). Metzler and Cicone (1983) have assessed different methods for classification of boundary pixels. The incorporation of boundary pixels in a separate signature, to be used in the classifier, has been a method of alleviating the boundary pixel problem (Mosher *et al*. 1978, Ryerson *et al*. 1981, Mergerson 1981). Unclassified boundary pixels within winter wheat fields were identified on the basis of a comparison of the field data and oblique, small format, color aerial photographs to the classified image displayed on the color

monitor. Appropriate pixels, selected on the basis of a subjective visual interpretation of the display, were used to create a separate winter wheat signature. This signature was used in the classification to create a theme representative of winter wheat boundary pixels.

During the 1982-83 growing season, unitemporal classification of Warner, Skiff and Foremost test segments was completed using spring data. Multitemporal classification was completed for the Warner test segment only. Unitemporal classification of Warner and Foremost test segments was completed using spring data of the 1983-84 growing season. Multitemporal classification was completed for the cloud free Taber segment and for the partially cloud inhibited Foremost segment. The cloud and thin haze contained in the fall image was variable in thickness throughout the Foremost test segment. The training areas used for the spring classification covered the variability of the winter wheat crop, therefore these training areas were used for the multitemporal classification which also took into account the variability of the cloud and thin haze over the test segment. Classification of a large geographical area was accomplished by utilizing training statistics obtained from within the test segments which were representative of the winter wheat growing conditions. These include consideration of changes in geographic and temporal conditions which may cause differences in signal level for single classes of interest.

3.4 Accuracy Assessment

There are two major types of accuracy assessment procedures: non-site-specific (total areal extent) and site-specific (location) (Mead and Szajgin 1982). Non-site specific accuracy is usually expressed as the similarity between the total number of hectares in each land-cover type as determined by a Landsat classification compared to the corresponding total area determined from measurements in the field. The purpose of estimating crops on an areal extent basis is not to determine the percent of pixels classified correctly, but, to determine the precision to which the crop area is estimated for the area of interest (Mergerson 1981).

The non-site-specific method compares only the total area without regard to location. In this case the total area classified as winter wheat was expressed as a percentage of the known winter wheat area in each segment. Site-specific accuracy, however, considers the spatial nature of the data when two spatially defined data sets (one ground truth) are registered and compared. The site-specific approach provides a more rigorous and more informative appraisal of the test segment classifications. Such comparisons can be made on a pixel basis and the percentage of correct, omitted and committed pixels are determined from a confusion matrix. An omission error occurs when a pixel is incorrectly excluded from a class while a commission error occurs when a pixel is incorrectly included in a class.

After the classification had been performed for a segment, the total number of pixels classified was calculated automatically. The number of committed and omitted pixels were determined manually based on the data collected in the field. The number of correctly classified pixels was determined by subtracting the number of committed pixels from the total classified. For this study the calculation of percent correct, omission and commission errors included pixels within those fields selected for signature generation. This will bias percent correct upwards.

3.5 Post-classification Filtering

When multitemporal Landsat data are not available for crop identification studies, the classification errors, caused by the similarity of spectral responses among classes on a unitemporal Landsat pass, may be diminished by the application of a post-classification filtering technique.

Goldberg *et al.* (1975) applied a spectral filter to an agricultural area improving the overall classification. Moreira *et al.* (1983) applied a post-classification 3 X 3 pixel filter resulting in a statistically significant reduction in errors of ommission and commission. Letts (1979) utilized an algorithm implemented in the AIRIES image analysis system for identifying small isolated areas in digital thematic maps and selectively replacing them with their (weighted) most frequently occurring neighbours. The

identification process successively scans the thematic map in alternating vertical directions until each pixel has been completely defined by the size of the area to which it belongs. The final output is an area size map which can be overlaid on the original thematic map. The replacement of selected areas is performed in a single simultaneous scan of the thematic map and the area size map. Pixels which lie in areas less than the specified minimum size for their corresponding themes are assumed to be unclassified, and the resulting unclassified areas are then replaced in successive steps.

Each test segment classification for the 1982-83 growing season was subjected to the small area replacement algorithm to determine the accuracy change and the overall effectiveness of such a technique.

4. RESULTS and DISCUSSION

Data for the 1982-83 winter wheat growing season are presented in two major sections: segment classification and signature extension. Each section is subdivided into site-specific and non-site-specific accuracy assessments. An additional subsection, within the signature extension section, deals with the assessment of signature extension between and beyond the respective test segments.

Post-classification filtering was conducted, using the 1982-83 winter wheat data to illustrate the effect of a subjective technique on accuracy assessment.

4.1 Segment Classification

4.1.1 Non-site-specific

Classification of the 1982-83 spring data for Foremost, Skiff and Warner test segments resulted in estimation errors. (Table 6). Overestimation error resulted when pasture, roughland and early seeded spring cereals within each segment had similar spectral responses as winter wheat in the spring. Multitemporal classification of the Warner test segment resulted in an 8% overestimation. Thus, the classification using multitemporal imagery resulted in a more accurate total area estimation as evidenced by a reduction in the overestimation error from 62 to 8 percent.

Classification accuracy assessment of the Warner, Foremost and Taber test segments ranged from zero to 75%

Table 6. Non-site-specific accuracy assessmemt for the total area of winter wheat in each test segment for 1982 - 83.

	Spring Data			Spring and Fall Data
	Foremost	Warner	Skiff	Warner
Total Area (ha)	9065	9324	9324	9324
% Winter Wheat (ground truth)	12	13	12	13
% Winter Wheat (classified)	13	21	11	14
% Estimation Error	8	62	- 8	8

overestimation using spring data for the 1983-1984 winter wheat growing season (Table 7). Within the Foremost segment pasture, roughland and early spring seeded barley were classified as winter wheat. Irrigated forages and moist to wet roughland areas were classified as winter wheat within the Taber segment. Classification of multitemporal imagery resulted in a more accurate total estimation as evidenced by the reduction in percent overestimation of Foremost and Taber segments from 6 to 0% and 75 to 13%, respectively.

4.1.2 Site-specific

Accuracy assessment of winter wheat classification on a location basis is important in determining and assessing crop condition and winterkill.

The percent correct and percent omission errors for single date classification using the 1982-83 data were similar for each segment (Table 8). A slightly lower percent correct and higher percent omission error for Warner resulted from a greater number of unclassified boundary pixels in this segment. Fields are generally smaller in Warner (average 29 hectares) than in Skiff (36 hectares) or Foremost (40 hectares). Small fields have a greater number of boundary pixels than larger fields, while very small fields (less than 10 hectares) are comprised entirely of boundary pixels (Pitts and Badhwar 1980). This was apparent in Warner and Foremost where 94 and 83%, respectively, of all omitted winter wheat pixels were boundary pixels. In all

Table 7. Non-site-specific accuracy assessment for the total area of winter wheat in each test segment for 1983 - 84.

	Spring Data			Spring and Fall Data	
	Warner	Foremost	Taber	Foremost	Taber
Total Area (ha)	9324	9065	9324	9065	9324
% Winter Wheat (ground truth)	13	17	8	17	8
% Winter Wheat (classified)	13	18	14	17	9
% Overestimation	0	6	75	0	13

Table 8. Site-specific accuracy assessmemt for the identification of winter wheat pixels in each test segment for 1982 - 83.

	Spring Data			Spring and Fall Data
	Foremost	Skiff	Warner	Warner
No. of Winter Wheat Pixels	4904	5001	5761	5761
% Correct Classification	90	88	87	84
% Omission Error	10	12	13	16
% Commission Error	8	14	37	12

segments, fields with relatively light vegetative cover were not entirely classified. These fields (Figure 4 and 5 field A, Figure 6 field A) were not fertilized and crop growth was relatively poor in the spring. A grasshopper infestation reduced the vegatative cover of fields A and B (Figure 7).

Single date classification commission errors were considerably higher for the Warner segment (Table 8). Approximately 27% of the total area of the Warner segment is pasture and roughland with portions having spectral signatures similar to winter wheat in the spring. The classification for Warner using multidate data resulted in a substantial reduction in the percent commission errors (Table 8). Although the pasture and roughland areas were spectrally similar to winter wheat in the spring, their fall signatures were sufficiently different allowing crop differentiation.

One field in Foremost presented a dilemma with respect to the accuracy assessment for this segment (Figure 6 field B). This field had not been intentionally seeded to winter wheat in the fall of 1982, although it had been winter wheat in 1981-82. Grain, left in the field after harvest in August 1982 germinated in the fall. The result was a field of volunteer grain in which 76 of 112 pixels were classified as winter wheat using the 1983 spring data. For the accuracy assessment these pixels were considered to be classified correctly even though the farmer indicated his intention to turn the crop under in June, 1983. The question arises

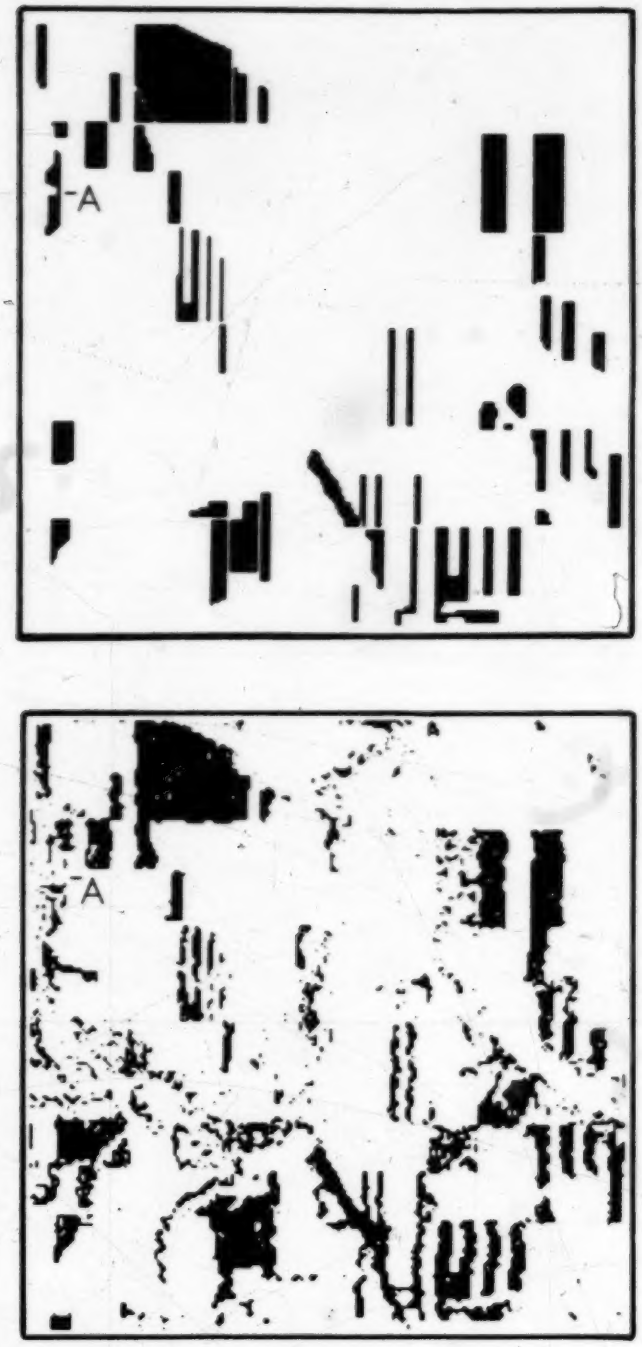

Figure 4. The Warner test segment: Top - Location and geometry of ground truthed winter wheat fields; Bottom - classification using spring data. Field A - unfertilized winter wheat with omission errors.

Figure 5. The Warner test segment: Top - Location and geometry of ground truthed winter wheat fields; Bottom - Classification using multidate data Field A - unfertilized winter wheat with omission errors, Field B and C - examples of increased omission errors after multidate classification.

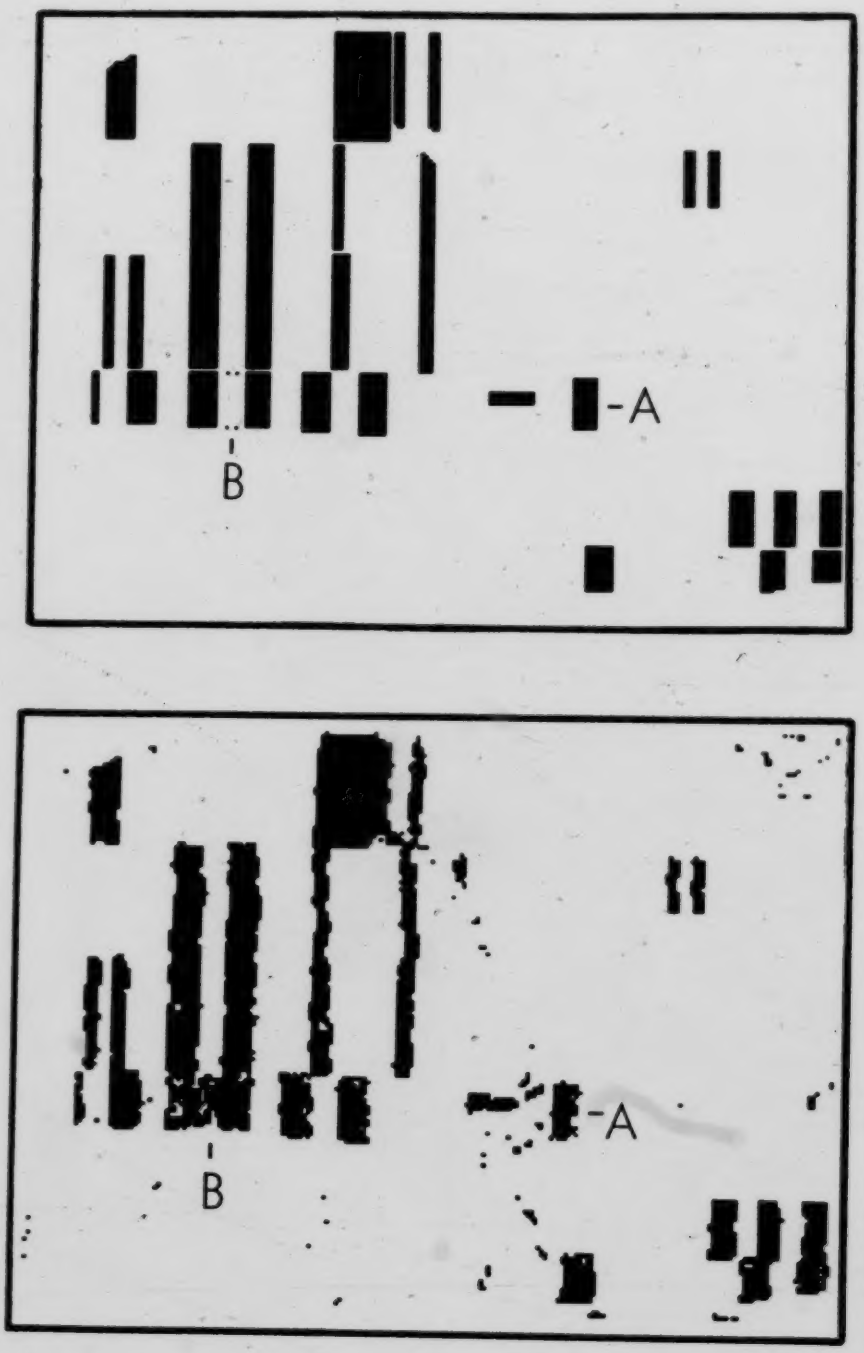

Figure 6. The Foremost test segment: Top - Location and geometry of ground truthed winter wheat fields; Bottom - classification using spring data. Field A - unfertilized winter wheat with omission errors; Field B - volunteer winter wheat.

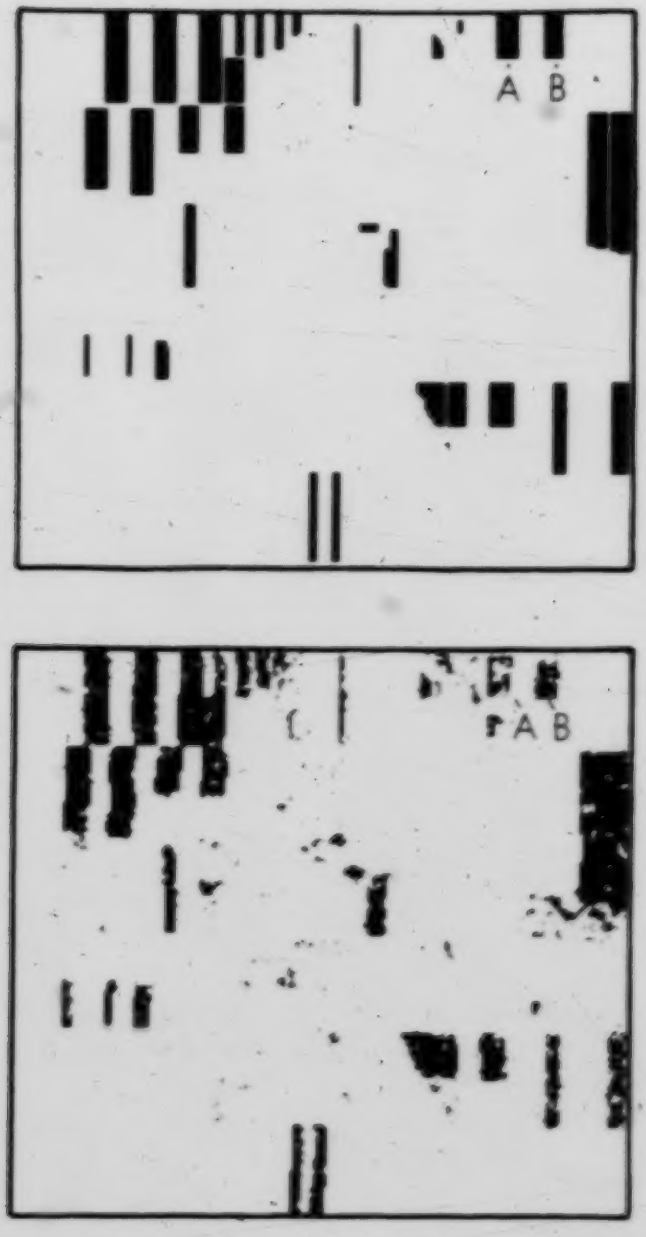

Figure 7. The Skiff test segment: Top - Location and geometry of ground truthed winter wheat fields; Bottom - classification using spring data. Fields A & B - infested with grasshoppers in the early spring.

concerning the 36 unclassified pixels in this field and whether or not they should be considered omission errors. In a seeded field, seed is distributed uniformily and at a constant rate while in a field of volunteer grain, the amount and distribution of seed varies with the density of the previous year's crop and harvesting methods employed. Therefore, it is conceivable that unclassified pixels are not omitted winter wheat pixels. Rather they represent portions of the field where there was no winter wheat. Since only one small field was involved the effect on the accuracy assessment of the spring classification was minimal (less than 1%). Such an occurrence could have a significant influence on the estimation of winterkill if a summer image were compared to a spring image to identify plantings which had been turned under.

The use of multidate data for Warner resulted in a 4% decrease in the percent correct and a corresponding increase in percent omission errors. The multidate data correctly classified fewer boundary pixels (Figure 5 fields B and C). These unclassified areas were along fields where grass and shrubs grew within fencelines, drainage ditches and road allowances. The greater vegetative cover in these areas in the fall produced a sufficiently different spectral response compared to the stubble or minimal green vegetative cover of winter wheat.

Variable results were obtained when the assessment of the 1983-84 data was completed using only the spring data

(Table 9). Portions of narrow fields were unclassifiedin the Warner segment. The average field size was 23 hectares with 92% of all unclassified winter wheat pixels being boundary pixels. Foremost had an average field size of 39 ha with 76% of all unclassified winter wheat pixels being boundary pixels. Four fields, constituting 105 hectares, were not completely classified due to poor vegetative cover (Figure 8 field A,B,C and D). Field D was seeded into canola stubble in the fall when field moisture reserves were low. The field had been broken from pasture the previous year and was worked extensively for the seeding rendering the soil susceptible to wind erosion. During the early spring, strong winds removed top soil and exposed the winter wheat crown tissue. Plant mortality was high and percent omission increased due to a lack of sufficient winter wheat cover. The remaining three fields, all belonging to the same producer, were poor stands of winter wheat resulting from a lack of fertilizer in the fall and spring. In addition, one field had a 50 m strip of spring wheat seeded in the centre. Resampling the digital data to 50 meters may have included portions of the winter wheat with the late seeded spring wheat decreasing the spectral homogeneity of the winter wheat pixel, resulting in omission errors.

High and low percent commission errors for Warner (16%) and Foremost (5%) were attributed to the percentage of roughland and pasture within the test segments. Warner contained 27% while Foremost contained 15 percent.

Table 9. Site-specific accuracy assessment for the identification of winter wheat pixels in each test segment for 1983 - 84.

	Spring Data			Spring and Fall Data	
	Warner	Foremost	Taber	Foremost	Taber
No. of Winter Wheat Pixels	5567	7511	3347	7511	3347
% Correct Classification	74	82	89	81	81
% Omission Error	26	18	11	19	19
% Commission Error	16	5	48	5	17

Figure 8. The Foremost test segment: Top - Location and geometry of ground truthed winter wheat fields; Bottom - classification using spring data. Fields A, B & C - unfertilized winter wheat with omission errors. Field D - winter wheat seeded into standing canola stubble with omission errors.

Spring classification of the Taber segment resulted in a high percent correct and a low percent omission error (Table 9). One field of winter wheat within the Taber test segment was partially omitted as a result of a poor stand. High percent commission error (48%) was due to the spectral signature of the winter wheat classifying irrigated alfalfa fields, irrigated pastures, low lying moist roughland and early spring seeded cereals. These fields were irrigated early in the spring to provide optimum growing conditions and resulted in lush vegetative ground cover spectrally responding the same as winter wheat. Within the irrigated sector, which comprises 34% of the segment area, 74% of the commission errors were recorded. One non-irrigated field of alfalfa was partially classified as winter wheat (Figure 9 field A). Sufficient springmelt water and a southern exposure gave the alfalfa a growing advantage in the spring.

Classification of multitemporal data for Taber resulted in a decrease of 8% correct with a corresponding increase of percent omitted over the unitemporal classification (Table 9). The decrease of percent correct resulted when the narrow winter wheat fields, comprised entirely of boundary pixels, and poorly vegetated winter wheat fields were not classified. Four poorly vegetated winter wheat fields intended for forage production were not seeded until the end of April of the following spring (Figure 10). Volunteer fall rye produced sufficient ground cover within these fields to produce a signature similar to the winter wheat in the fall.

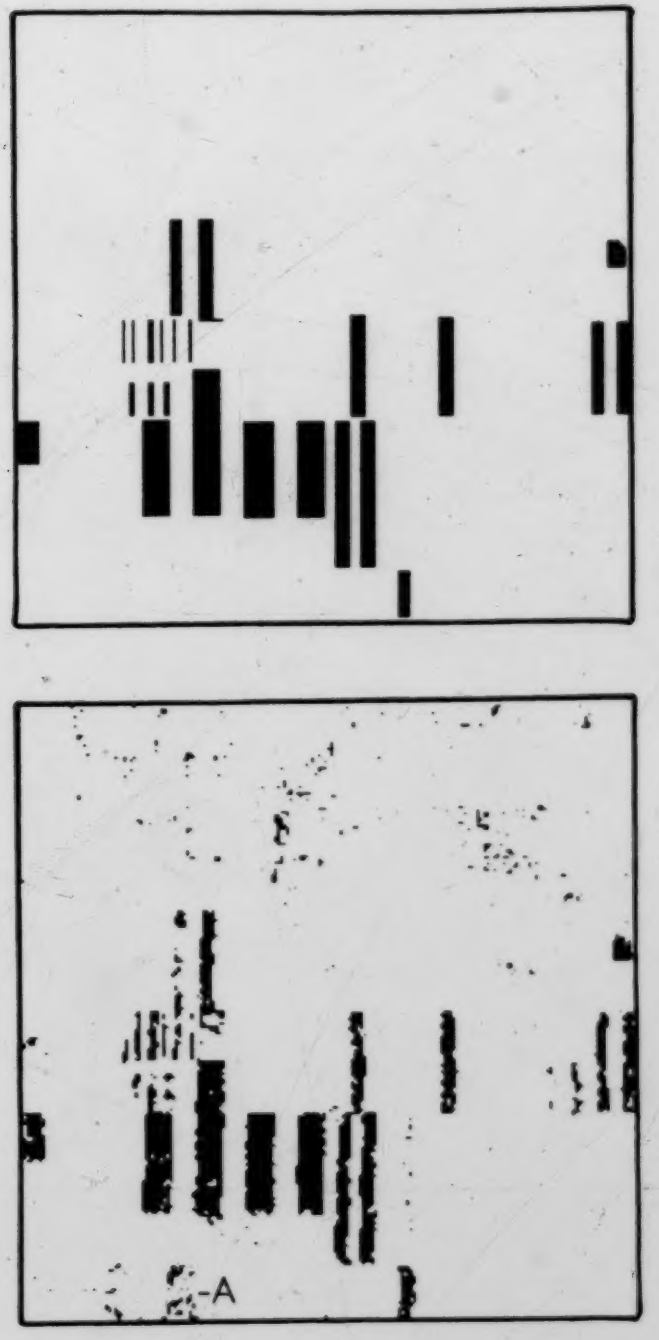

Figure 9. The Taber test segment: Top - Location and geometry of ground truthed winter wheat fields; Bottom - classification using multi-date data. Field A - Alfalfa field committed as winter wheat.

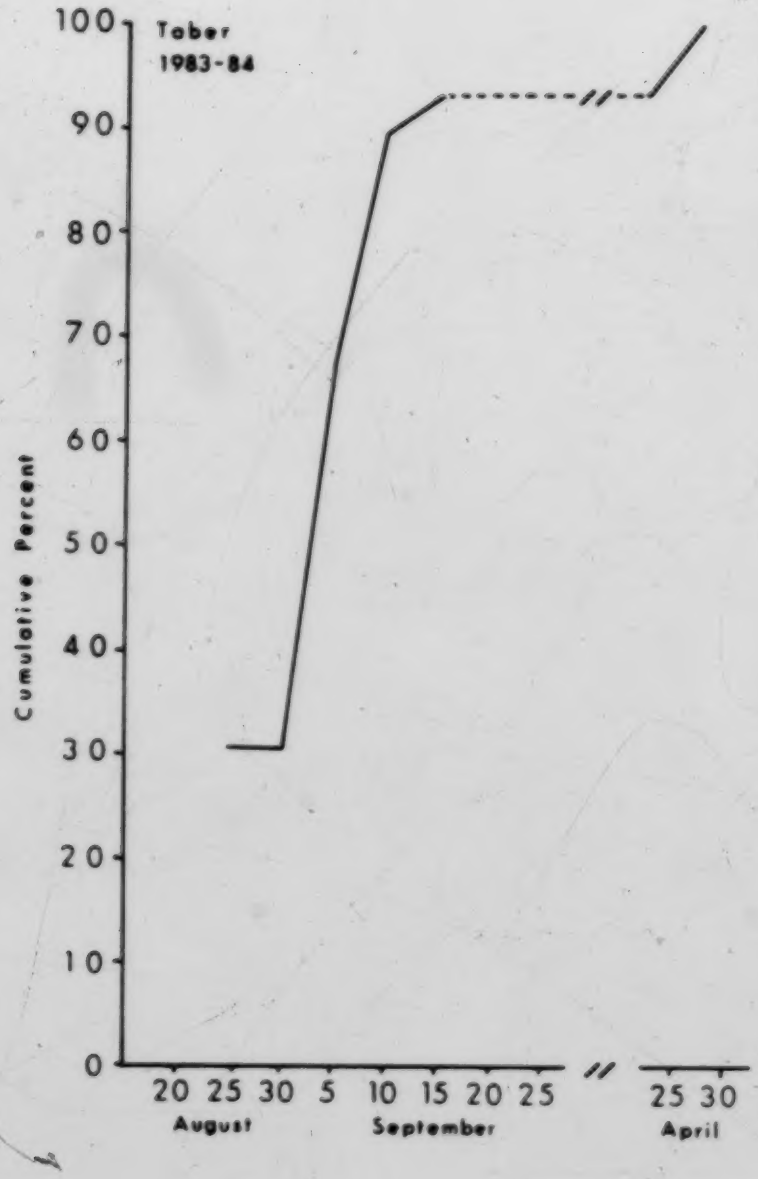

Figure 10. Winter wheat seeding dates for the Taber test segment, 1983 - 84.

However, the ground cover was not as uniform as would be attained from seeded winter wheat. A lack of fertilizer at the time of seeding also contributed to the problem of an incomplete non-uniform vegetative cover of these fields resulting in abnormal reflectance values being recorded. The average field size of the four fields was 9 hectares. An increase in boundary pixel omission attributed to the overall higher omission error. The precision of overlaying the data is influenced by the accuracy when geometrically correcting the MSS data to the UTM grid. Residual errors of less than 1/4 pixel for both dates were attained. However, if the offset of the pixels in each scene were in opposite directions, the boundary pixel problem will be compounded when using multidate data. Changes of interest are often interspersed with false changes due to misregistration (Colwell 1983). An increase in boundary pixel omission errors of 5% for Warner during 1982-1983 and a 3% increase for Taber, during the 1983-1984 growing season were noted when multitemporal data were used. The advantage of using multitemporal data is exemplified in the decrease of the percent commission error from 48 to 17% for the Taber test segment (Table 9).

Light cloud cover and haze at the time of the fall image presented a problem at Foremost for attaining an increase in classification accuracy using multitemporal data. A 1% decrease in correctly classified winter wheat with a corresponding increase in percent omission error

resulted when cloudy multitemporal data were used (Table 9). There was no change in the percent commission error. Portions of fields were not classified as the cloud and haze thickness were variable over the test segment. Multitemporal winter wheat signatures generated within the Foremost segment, classified portions of winter wheat fields similar to crop condition and haze thickness of the training areas. Unclassified winter wheat did not exhibit the same spectral characteristics as expressed by the multitemporal signatures used in Foremost.

4.2 Signature Extension

Signature extension is an attempt to reduce the total amount of analyst work required in making a winter wheat area estimate for a region. The approach implemented the extraction of signatures from one or more segments and apply these signatures to classify areas beyond the generation segment; hence, the term "signature extension".

4.2.1 Non-site-specific

The 1982-83 non-site-specific accuracy assessments of Skiff and Foremost, using the signature extension technique, were found to be variable (Table 10). Overestimation of the total winter wheat area was common. Variability in signature response between the two segments resulted in an 11% underestimation in the Foremost segment, using the Skiff signatures. The winter wheat fields within Skiff had less

Table 10. Percent estimation error of non-site-specific signature extension accuracy assessment for the total area of the winter wheat in each test segment, 1982 - 83 data.

Source signature	Test Segment Classified	
	Foremost	Skiff
Skiff	-11 %	+11 %
Foremost	+11 %	+ 1 %
Skiff & Foremost	+24 %	+18 %

fertilizer applied, compounded with a later seeding date (Figure 11 and 12). By September 10, 1982, 100% of all the winter wheat fields in Foremost had been seeded while 75% were seeded in Skiff with the remainder being seeded up to one month later. The Skiff segment contained poorer stands of winter wheat than Foremost, resulting in lower reflectance values of bands 6 and 7 and higher reflectance values of bands 4 and 5 (Table 11). The range of standard deviation for Foremost was greater in all four bands. Therefore, when the Skiff signatures were extended to the Foremost segment various winter wheat fields and portions of others were not classified. Within the Foremost segment, winter wheat rated as excellent was not classified (Figure 13 fields A,B,C,D and E) contributing to the underestimation of winter wheat using the Skiff signatures.

Classifying the Skiff segment using the Foremost signatures resulted in a favourable non-site-specific classification (Table 10). The Foremost signatures contained most of the range of reflectance values within bands 7,6,5 and 4 of the Skiff signatures (Table 11). In addition, the winter wheat signatures from Foremost had a greater standard deviation which allowed a broader classification of the Skiff winter wheat.

Classification of the Foremost and Skiff segment with both segment signatures resulted in an overestimation of the winter wheat (Table 10). Combined segment signatures provided a greater range of values outside the winter wheat

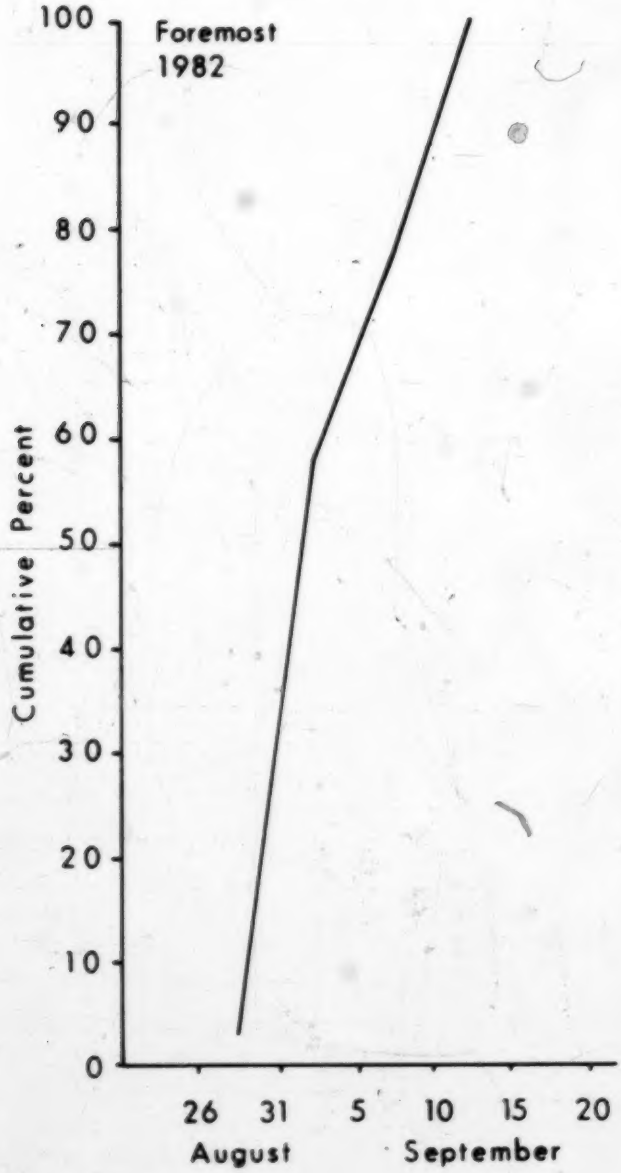

Figure 11. Winter wheat seeding dates for the Foremost test segment, 1982.

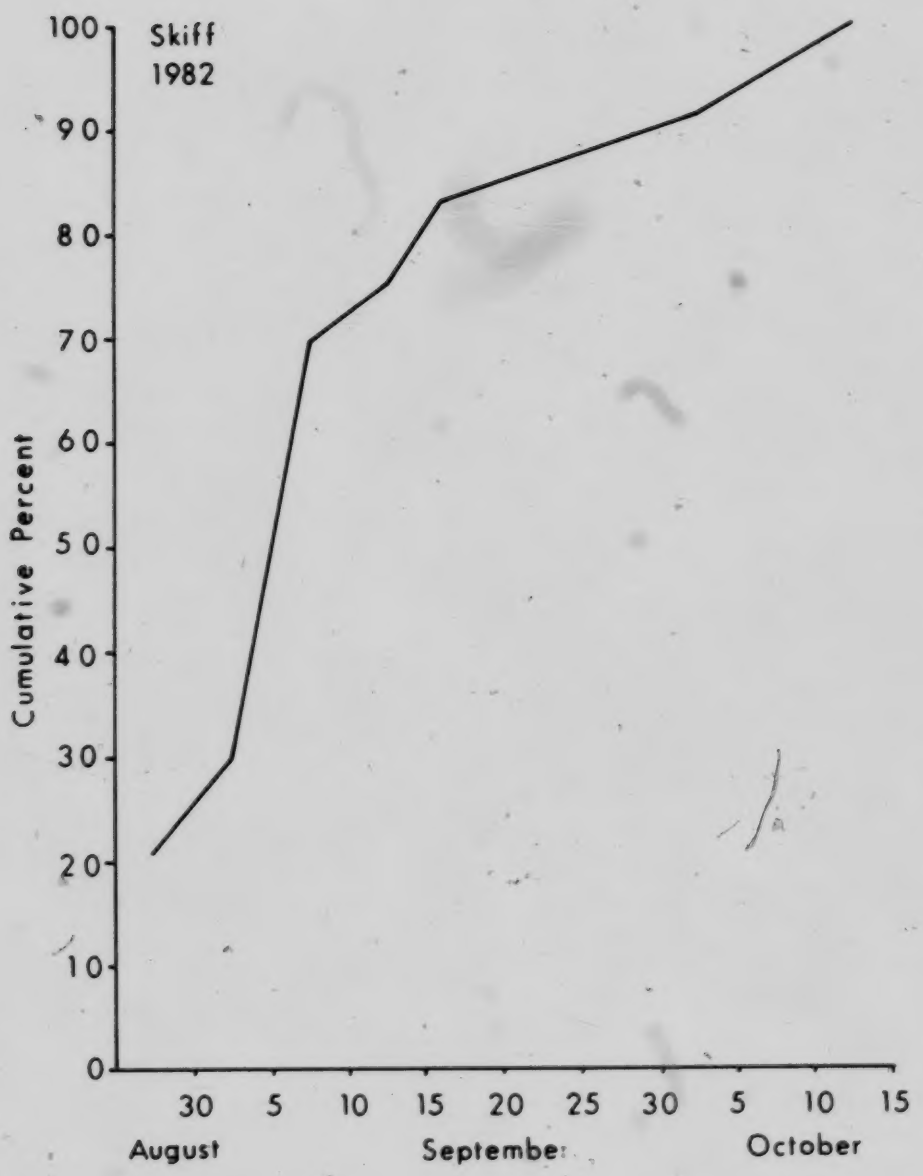

Figure 12. Winter wheat seeding dates for the Skiff test segment, 1982.

Table 11. Mean ($\bar{X}$) and standard deviation (σ) for bands 7,6,5 and 4 of winter wheat signatures within the Foremost and Skiff test segments.

Foremost May 28, 1983

Band 7		Band 6		Band 5		Band 4	
$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
198.95	13.39	181.43	11.68	80.46	8.84	95.32	8.02
254.68	1.62	241.25	10.01	50.43	7.05	80.70	8.74
165.38	8.34	151.78	7.03	87.79	9.41	98.62	9.39
220.04	19.19	184.70	13.81	54.39	12.48	70.81	10.84
234.47	18.42	217.24	17.96	62.97	9.20	90.56	9.11
220.32	22.63	207.49	22.60	87.32	26.11	106.03	19.86
178.60	36.37	192.15	30.21	53.35	10.55	79.95	12.09
236.91	23.57	201.00	24.28	66.27	25.76	77.36	21.91
Range							
165-255	2-37	152-241	7-30	50-88	7-26	71-106	8-22

Skiff May 28, 1983

Band 7		Band 6		Band 5		Band 4	
$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
158.34	10.29	140.79	8.22	82.21	6.47	91.79	10.99
203.42	21.48	174.79	13.30	74.49	15.99	88.88	14.52
173.03	5.94	159.38	5.38	91.77	7.44	101.96	7.87
163.40	10.42	142.94	7.11	65.71	7.64	75.96	7.53
178.56	26.68	194.22	15.24	70.00	10.04	82.89	10.08
197.00	15.92	171.45	21.01	103.82	20.02	113.73	26.95
181.10	6.78	160.13	6.61	71.38	5.53	83.65	7.00
Range							
158-197	6-27	143-194	5-21	70-104	6-20	76-114	7-27

Figure 13. The Foremost test segment: Top - Location and geometry of ground truthed winter wheat fields; Bottom - classification of the Foremost test segment using Skiff winter wheat signatures. Fields A, B, C, D & E - areas of unclassified winter wheat rated as excellent stands.

threshold within each segment. The increased error resulted when pasture and early spring seeded cereals had similar spectral responses as the extended range of winter wheat signatures and were subsequently classified.

Classification of the Foremost and Taber test segments, using the 1983-84 multitemporal data, resulted in varied estimation errors (Table 12). Signature extension between cloudy and cloud-free segments resulted in high underestimation errors. Foremost segment signatures did not overestimate the total winter wheat within the Foremost segment. Within segment overestimation occurred when the Taber segment was classified using the Taber winter wheat signatures. Areal overestimation occurred when portions of irrigated pasture and irrigated alfalfa fields were classified. Combining both segment signatures resulted in an overestimation of both segments as pasture and roughlands were partially classified. The Foremost segment was overestimated by 6% when the Taber segment signatures were included with the Foremost signatures. The Taber segment was overestimated by an additional 9% over that incurred by using only the Taber signatures. Increased overestimation of each segment occurred as a result of the winter wheat signature range being broadened by including both signature sets to classify one segment. Additional pasture and rangeland within each segment were classified as a result of the broader winter wheat signature. Overestimation was greatest in Taber due to the increased vegetative growth in

Table 12. Percent estimation error of non-site-specific signature extension accuracy assessment for the total area of winter wheat in each test segment using multitemporal data for 1983 - 84.

Source Signature	Test Segment Classified	
	Foremost	Taber
Foremost	0 %	- 50 %
Taber	- 59 %	+ 11 %
Foremost & Taber	+ 6 %	+ 20 %

the spring and fall brought on by irrigation.

4.2.2 Site-specific

The 1982-83 site-specific accuracy assessment of the Skiff segment, classified using the Foremost signature, indicated favourable results with 82% of the winter wheat correctly classified, 18% omitted and 12% committed (Table 13). Variations in crop condition between the two segments resulted in the high omission error with portions of several winter wheat fields not being classified (Figure 14 fields A,B and C). Commission error were predominantly in pasture and roughland. Farmyards with large lawns and sod covered implement work areas were also committed to winter wheat. In the Foremost segment, winter wheat fields were more intensively managed with fewer producers being involved. Seeding dates were extended over a longer period of time within the Skiff segment, in addition less phosphate and nitrogen fertilizers were used during seeding and spring applications resulting in lighter vegetative cover at the time of imaging.

The difference between spectral signatures for winter wheat in the Skiff and Foremost segments was further emphasized by the results of classifying Foremost with Skiff winter wheat signatures (Table 14). The commisson error was high and percent correctly classified was low. One entire field and portions of others were not classified (Figure 13 fields A,B,C,D and E). These unclassified winter wheat areas

Table 13. Site-specific signature extension accuracy assessment of the Skiff test segment for 1982 - 83.

	Classified with Skiff signatures	Classified with Foremost signatures	Classified with Foremost & Skiff signatures
% Correct	88	82	92
% Omitted	12	18	8
% Committed	14	12	16

Figure 14. The Skiff test segment: Top - Location and geometry of ground truthed winter wheat fields; Bottom - classification of the Skiff segment using Foremost winter wheat signatures. Fields A, B & C - winter wheat fields with omission errors.

Table 14. Site-specific, signature extension accuracy assessment of the Foremost test segment for 1982 - 83.

	Classified with Foremost signatures	Classified with Skiff signatures	Classified with Skiff and Foremost signatures
% Correct	90	67	94
% Omitted	10	33	6
% Committed	8	15	13

were rated as excellent stands during ground surveys. The Skiff segment did not contain winter wheat of excellent rating, therefore the signatures did not contain the required spectral information to classify this class within the Foremost segment. The poorer stands of winter wheat were classified within the Foremost segment since signatures generated within Skiff were from comparable winter wheat stands.

The highest % correct and lowest % omission error for Skiff occurred when the Skiff and Foremost signatures were combined. The commission error, however was 13 percent. The increase in % commission error was due to the broader spectral signature range resulting in additional forages and pasture being classified.

Experience with signature extension between test segments for the 1982-1983 winter wheat growing season revealed that signature extension involved both segment signatures to classify each test segment. Increased percent correctly classified with a corresponding decrease in percent omitted errors were noted in Taber and Foremost segments when both segment signatures were applied to each segment using the 1983-84 data (Table 15). In Taber, one poorly vegetated winter wheat field was classified more completely when both segment signatures were employed. However, one field of spring wheat, seeded 5 weeks prior to the spring imaging date, was partially classified. Numerous pixels within the irrigated alfalfa and pasture of the Taber

Table 15. Site-specific signature extension accuracy assessment of the Taber and Foremost test segments for 1983 - 84.

Taber

	Classified with multitemporal Taber signatures	Classified with multitemporal Foremost & Taber signatures
% Correct	81	88
% Ommitted	19	12
% Committed	17	24

Foremost

	Classified with multitemporal Foremost signatures	Classified with multitemporal Foremost & Taber signatures
% Correct	81	86
% Ommitted	19	14
% Committed	5	6

segment were classified as winter wheat. The 7% increase in correctly classified winter wheat was offset by a 7% increase in commission error when the Foremost multitemporal signature was used in addition to the Taber signature. The percent offset was a result of the cloudy quality of the Foremost multitemporal data.

Classification of the Foremost segment using Taber and Foremost multitemporal data resulted in a 5% increase in correctly classified winter wheat with a corresponding decrease in omission error. Winter wheat fields that were not under cloud and haze were not completely classified by the multitemporal signature generated in Foremost. The inclusion of Taber multitemporal signatures allowed these atmospherically unobstructed winter wheat fields to be more fully classified since Taber did not have thin cloud and haze over the segment during either imaging date. Foremost contained less pasture, roughland and no irrigated fields of alfalfa or pasture, therefore less area was committed as winter wheat in comparison to Taber (Table 15).

4.2.3 Large Geographical Area

Classification of 7336 km² within the winter wheat growing area was completed using the 1982-83 data. Highest % correct and lowest % omitted errors were obtained when two sets of segment signatures were combined to classify one test segment (Table 8 and 9). Therefore, to maximize correctly classified winter wheat pixels, signatures from

both segments were used to cover the variability within the winter wheat crop. Site-specific accuracy, using the signatures from the Skiff and Foremost segments, should result in correct identification of approximately 93% with commission errors predominantly from pasture.

Classification of the large geographical area, using Skiff and Foremost signatures resulted in correctly classifying 39 of 42 (93%) blind-site fields. No rigorous determination of commission errors could be performed as field data on all winter wheat fields in the entire area were unavailable. However, five fields of fall rye (400 ha) and pastureland within the Milk River Ridge were also classified as winter wheat.

During the 1983-84 period of operation, a multitemporal classification of a large geographical area (13,506 km^2) was completed using winter wheat signatures from Foremost and Taber test segments. This classification should result in approximately 84% of the winter wheat being correctly classified with approximately 11% of the commission error resulting from pasture and roughland in dryland regions with a higher proportion in regions of irrigation (Table 9).

Classification of the large geographical area resulted in 573 of 606 (94%) blind-site winter wheat fields being correctly classified. Sixteen of the total blind-site fields, located in close proximity to each other, were fall rye of less than 80 m in width. Field width was also a problem with several winter wheat fields. Sufficient ground

cover was not available to produce a signature within the range of the training area data used resulting in classification omission of these fields. One irrigated field of alfalfa was committed to winter wheat. Sufficient water was supplied in the fall and spring allowing the forage crop to have optimum growth which reflected and absorbed the electromagnetic spectrum in a manner similar to winter wheat. Two omitted fields of winter wheat, with a variable row spacing of 40 and 20 cm, had been seeded into canola stubble. The 40 cm spacing was sufficient to allow soil and canola stubble reflectance to influence the signature of this winter wheat field so that it was outside of the range of signatures generated. None of the training areas used had these characteristics to classify such a field of winter wheat. Three durum wheat fields were inter-dispersed with volunteer winter wheat resulting in an non-uniform classification. These fields were of low percent ground coverage in the fall and were seeded to wheat in the spring. The spectral characteristics of these fields did not meet the criteria of the crop calendar used in multitemporal classification. Two pastures, enclosed for grazing purposes, were also committed as winter wheat. Grazing removed dead plant material in the fall. Termination of grazing early in the fall allowed a stand of grass for overwintering which took advantage of the springmelt and produced a healthy vegetative cover in the spring. Healthy vegetative cover in the fall and spring were spectrally similar to winter wheat

resulting in the pasture areas being committed as winter wheat. Nine other fields that were blind-site fields were not completely classified or were completely omitted due to cloud, cloud shadow and haze contained on the fall image. The winter wheat signatures of the Foremost segment did not take into account all the winter wheat crop conditions under all the possible cloud, cloud shadow and haze conditions encountered within such a large geographical area.

The difference between site-specific accuracy (84%) and the blind-site accuracy (94%) of the large geographical area is a result of comparing detailed point by point information with a broad classification of non-site specific data. For the latter, winter wheat fields are assessed visually to determine if they meet the interpreter's scrutiny of being classified and considered as a correctly classified winter wheat field. Kolm and Case (1984) set a minimum error criterion level at 80 percent accuracy for "proper" crop-type identification (known crop area versus classified area). The same criterion level was used here, any blind-site fields that appeared to be less than this criteria were not considered correctly classified.

Boundary pixels are less of a problem in assessing accuracy in non-site-specific than in a site-specific classification. Classified field geometry remains the same when boundary pixels are not comprising the entire winter wheat field, thereby simplifying the recognition of a classified winter wheat field to a two class decision (yes

or no) when using the minimum error criterion level.

4.3 Post-classification Filtering

Improvements in crop classification results using spatial class filtering for post-classification were noted by a higher percentage of correct classification, a smaller error of commission and a more accurate areal estimate (Moreira *et al.* 1982).

Site-specific accuracy results for post-classification filtering (custering), applied to the data from the 1982-83 winter wheat growing season, illustrate an average percent commission error decrease of 4% (Table 16). The test segments containing greater percentages of roughland had higher percentages of commission error removed from within pasture and roughland. Percent correctly classified increased by 1 to 2% for Skiff and Foremost. The increase resulted from infilling unclassified pixels within winter wheat fields. The unclassified pixel must be completely surrounded with pixels classified as winter wheat for infilling to occur.

A 1% decrease in correctly classified pixels occurred in the Warner test segment (Table 16). A greater percentage of correctly classified winter wheat pixels were removed in comparison to the amount of omitted pixels that were filled in. The Warner test segment contained narrow fields composed entirely of boundary pixels, that were not completely classified. Consequently when the filtering technique was

Table 16. Site-specific accuracy assessment comparisons of unfiltered versus filtered post-classification analyses for Warner, Foremost and Skiff segments for 1982 - 83.

	Unfiltered	Filtered
Warner(multitemporal)		
% Correctly classified	84	83
% Omission error	16	17
% Commission error	12	6
Foremost(unitemporal)		
% Correctly classified	90	91
% Omission error	10	9
% Commission error	8	6
Skiff(unitemporal)		
% Correctly classified	88	90
% Omission error	12	10
% Commission error	14	11

applied, classified portions of these narrow fields conformed to the filtering parameters and were eliminated. A 6% decrease in commission error offset the 1% decrease in correctly classified winter wheat as a result of post-classification filtering.

Care and caution must be exercised when implementing post-classification filtering. The technique is very sensitive to the threshold values input prior to filtering. Results of the filtering technique may be aesthetically pleasing, however the process is very subjective. Each segment may require different values for the filtering algorithm to produce acceptable results. Portions of field interiors that were not classified in the initial classification may not be winter wheat but perennial sloughs or areas of winterkill. Implementing this technique may nullify the purpose of the project. Post-classification filtering will infill the unclassified pixels as winter wheat presenting a uniformly classified winter wheat field with commission errors.

Accurate ground truth data, supplemented with aerial photographs of the test segments, are required to determine the commission errors resulting from infilling of non-winter wheat pixels such as sloughs, rock piles etc. and the ommission errors resulting from eliminating correctly classified winter wheat pixels.

5. SUMMARY

Analysis of Landsat MSS digital data for the identification of winter wheat resulted in varied non-site-specific or total area estimations. Spring data classification errors were in the order of ± 8% except for test segments that contained greater than 25% of pasture and roughland (+62%) or irrigated farmland (+75%). Multidate data improved the total area estimates reducing these errors from 62 to 8% in the former and 75 to 13% in the latter.

Accuracy assessment of winter wheat classification on a site-specific or location basis is important if assessments of crop conditions and in particular areas of winterkill are to be made. The aggregate unitemporal correct classification ranged from 74 to 90 percent. Percent commission error (5-48%) varied from test segment to segment increasing with an increase in the proportion of pasture and roughland (6-27%) or irrigated farmland. Farm management, especially fertilizer application rates, also influenced the winter wheat classification as correct identification increased with increased crop vigour.

Classifications using multidate data resulted in an average decrease of 6% in correctly classified winter wheat pixels. Current literature does not mention the percent decrease in accuracy assessment when using multidate data. Percent decrease was compounded by the multidate registration error, boundary pixels and the poor spatial resolution of the Landsat MSS system relative to the narrow

fields in southern Alberta. However, the average 28% decrease in commission error compensates for the above decrease in percent correctly classified.

The extension of one set of signatures to another test segment for total area classification did not classify the test segment as accurately as the signatures developed within the test segment. Combining signature sets from both segments consistently overestimated the amount of winter wheat within the respective test segments. Site-specific signature accuracy assessments revealed that the highest % correct identification and highest % commission were attained when applying several segment signature sets to one segment.

Spectral signatures for winter wheat developed within the test segments for 1982-83 and 1983-84 were extended to classify 7336 km^2 amd 13,506 km^2; respectfully. Based on a comparison to "blind site" data an average of 93% correct identification for the location of winter wheat was achieved over the two year study period. No rigorous determination of commission errors could be performed as field data on all winter wheat fields were unavailable.

Post-classification filtering resulted in a higher percent correct classification and a smaller commission error provided small fields of less than three pixels in width were not included.

6. CONCLUSIONS

A relatively unique crop calendar combined with Landsat digital data provides for the identification of winter wheat on both a total area and a location basis. Accuracy assessment for the latter is tedious and time consuming but is necessary for meaningful data. Models for the total area are not directly applicable when location is of equal importance.

The results confirm the primary importance of spring imagery although omission and commission errors occur. Results of spring data analyses are accurate provided confusion crops, pasture and irrigation do not occur. In addition, data acquisition must be late enough in the spring to take advantage of the advanced green vegetative winter wheat cover and early enough to eliminate misclassification by confusion cover crops. Multitemporal data are essential for agricultural remote sensing analyses where areas are known to include pasture, roughland and irrigation. Multitemporal data improved the classification accuracy by significantly reducing commission errors but their use resulted in a slight increase in ommission errors. The latter was compounded by boundary pixels and poorly vegetated winter wheat fields. Creating broader winter wheat signatures to include boundary pixels could increase commission errors. The major problem arises from the poor spatial resolution of the Landsat MSS system relative to the narrow fields in southern Alberta.

Single segment signature extension does not consistently classify the total area or the location of winter wheat due to the variation in spectral values when the area of interest begins to expand beyond the original segment. Multi-segment signature extension correctly classified more of the winter wheat within the test segments, however an equal increase in confusion crops were also classified. Even though winter wheat spectral reflectance patterns are not stable from one segment to another, signatures from a collection of segments maintain their discriminating properties.

The results confirm the potential for mapping and monitoring winter wheat over a large geographical area. Development of the winter wheat model required several large test segments. Progression from a Research and Development to an on-line operational mode would require the implementation of more segments of smaller size to cover a larger land base representative of all the winter wheat variability found in southern Alberta. Segment sizes of approximately 7 km X 7 km would allow the above criterion to be met. Uniform distribution of the test segments throughout the winter wheat growing area would require approximately 26 ground truthed segments; 13 for signature generation and 13 for "blind site" accuracy assessment.

Research for the improvement of the winter wheat model would require MSS digital data augmented with simulated radar satellite data to eliminate the problem of cloud cover

and potentially reduce the confusion with pasture and roughland. This research is suited for immediate undertaking as Canada is in the final stages of developing a radar satellite to be launched in the very near future.

7. LITERATURE CITED

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8. APPENDIX

8.1 Land Use and Winter Wheat Summary

LAND USE SUMMARY

Warner 1983-84

Land use	Hectares	# Fields	% Total	% Crop Total
Winter Wheat	1198	53	12.9	24.2
Summerfallow	1857	84	19.9	----
Barley	527	12	5.7	10.7
Canola	180	6	1.9	3.6
Spring Wheat	2413	81	25.9	48.8
Pastures	531	8	5.7	----
Unknown	626	32	6.6	12.7
Unclassified	1992	--	21.4	----
Total	**9323**	**276**	**100.0**	**100.0**

WINTER WHEAT SUMMARY

Warner 1983-84

Hectares	Field Number	Seeding Date	%	Cum. %
388	35,77,120 124,129,131 210,240,249	Sept 6-10	33.8	33.8
158	155,185,187 189,191,193 195,197,199 244,246,247	Sept 11-15	13.7	47.5
246	43,45,86,93 95,172,176 213,215,217	Sept 16-20	21.4	68.9
358	19,21,54,61 63,99,100,103 105,107,110,112 114,161,169,184 225,228,264,266 268	Unknown	31.1	100.0
Total				
1150	**53 fields**		**100.0**	**100.0**

LAND USE SUMMARY

Taber 1983-84

Land use	Hectares	# Fields	% Total	% Crop Total
Winter Wheat	733	28	7.9	15.2
Summerfallow	2222	78	23.8	----
Barley	563	22	6.0	11.7
Mustard	543	18	5.8	11.3
Spring Wheat	2573	89	27.3	53.5
Peas	96	5	1.0	2.0
Sugar Beets	223	11	2.4	4.6
Potatos	79	3	0.8	1.6
Pasture	480	25	6.4	----
Unknown	1813	--	19.5	----
Total	**9325**	**279**	**99.9**	**99.9**

WINTER WHEAT SUMMARY

Taber 1983-84

Hectares	Field Number	Seeding Date	%	Cum. %
227	223,225,340	Aug 20-25	30.9	30.9
---	----------	Aug 26-30	----	----
356	281,283,291 296,298,300 304,356,360 364,368,370 437	Sept 1-05	48.6	79.5
65	326,332	Sept 6-10	8.8	88.3
45	266,391,393 270,272	Sept 11-15	6.1	94.4
40	285,286,288 289	April 25-30	5.5	99.9
Total				
733	**28 fields**		**99.9**	**99.9**

LAND USE SUMMARY

Foremost 1983-84

Land use	Hectares	# Fields	% Total	% Crop Total
Winter Wheat	1571	35	17.3	35.1
Summerfallow	3293	84	36.3	----
Barley	304	5	3.4	7.1
Mustard	168	4	1.9	3.9
Spring Wheat	1937	55	21.4	45.5
Flax	283	1	3.1	6.6
Pasture	1125	--	12.4	---
Unknown	384	12	4.2	---
Total	**9065**	**196**	**100.0**	**100.0**

WINTER WHEAT SUMMARY

Foremost 1983- 84

Hectares	Field Number	Seeding Date	%	Cum. %
50	169,191	Sept. 1-05	3.2	3.2
556	18,52,54,72 74	Sept. 6-10	35.4	38.5
429	65,67,69,99,120 123,127,129,161 171,173,177,193	Sept 11-15	27.3	65.9
190	90,92,94,96,210	Sept 16-20	12.1	78.0
346	21,23,45,47,48 50,184,200,202 204	Unknown	22.0	100.0
Total				
1571	**35 fields**		**100.0**	**100.0**

LAND USE SUMMARY

Warner 1982-83

Land use	Hectares	# Fields	% Total	% Crop Total
Winter Wheat	1240	43	13.3	25.1
Summerfallow	1847	78	19.8	----
Barley	1047	23	11.2	21.2
Spring Wheat	1903	71	20.4	38.5
Pastures	531	8	5.7	----
Unknown	749	37	8.0	15.2
Unclassified	2008	--	21.5	----
Total	**9325**	**260**	**99.9**	**100.0**

WINTER WHEAT SUMMARY

Warner 1982-83

Hectares	Field Number	Seeding Date	%	Cum. %
116	200,202,204 208,239,241	Sept 1-05	9.4	9.4
549	55,76,78,97 144,170,171 182,211,214 216,218,219 233,234,235 243,245,248 250	Sept 6-10	44.3	53.7
275	1,9,18,20,42 44,48,121,160 162,173,221	Sept 11-15	22.2	75.9
57	98,101,104	Sept 16-20	4.6	80.5
--	---------	Sept 21-25	---	---
243	11,12	Sept 26-30	19.5	100.0
Total				
1240	**43 fields**		**100.0**	**100.0**

LAND USE SUMMARY

Skiff 1982-83

Land use	Hectares	# Fields	% Total	% Crop Total
Winter Wheat	1155	32	12.4	24.5
Summerfallow	3863	123	41.4	----
Barley	310	12	3.3	6.6
Mustard	63	1	0.7	1.3
Spring Wheat	2915	97	31.3	61.7
Oats	49	3	0.5	1.0
Wheat Grass	6	1	0.1	0.1
Pasture	349	13	3.7	---
Unknown	224	10	2.4	4.7
Unclassified	390	--	---	---
Total	**9324**	**292**	**100.0**	**99.9**

WINTER WHEAT SUMMARY

Skiff 1982-83

Hectares	Field Number	Seeding Date	%	Cum. %
244	4,6,8,250	Aug 25-30	21.1	21.1
97	143,51,53	Sept 1-05	8.4	29.5
459	18,29,68,70 72,74,127 246,321,322 323,156,264 266	Sept 6-10	39.7	69.2
70	10,12,14,16 35,37	Sept 11-15	6.1	75.3
91	232,237,239	Sept 16-20	7.9	83.2
--	----------	Sept 21-25	---	---
--	----------	Sept 26-30	---	---
97	116	Oct 6-10	---	---
--	----------	Oct 6-10	---	---
97	115	Oct 11-15	8.4	100.0
Total				
1155	**32 fields**		**100.0**	**100.0**

LAND USE SUMMARY

Foremost 1982-83

Land use	Hectares	# Fields	% Total	% Crop Total
Winter Wheat	1077	27	11.9	24.8
Summerfallow	3354	81	37.0	----
Barley	425	3	4.7	9.8
Mustard	291	4	3.2	6.7
Spring Wheat	2336	67	25.8	53.9
Oats	32	2	0.4	0.7
Flax	97	1	1.0	2.3
Pasture	1375	--	15.1	---
Unknown	77	3	0.9	1.8
Total	**9064**	**188**	**100.0**	**100.0**

WINTER WHEAT SUMMARY

Foremost 1982-83

Hectares	Field Number	Seeding Date	%	Cum. %
30	196	Aug. 26-31	2.8	2.8
594	19,20,22,53,55 168,170,172 192,194,198	Sept. 1-05	55.8	58.0
206	6,66,126,128 190	Sept. 6-10	19.1	77.1
246	60,81,83,93,95 100,122,124 145,146	Sept 11-15	22.9	100.0
Total				
1077	**27 fields**		**100.0**	**100.0**

8.2 Segment Field Number and Crop Cross Reference

Field identification numbers and associated crop type for all segments during the study period are listed below. Corresponding segment maps are provided in the Appendix. Crop codes are as follows:
WW- winter wheat, SW - Spring wheat, BY - Barley, CN - Canola, SF - Summerfallow, FL - Flax, OT - Oats, CO - Corn, SB - Sugar beets, FG - Forage, PT - Potatoes, UK - Unknown, PA - Pasture, (--) - No field of corresponding number. Fields with alpha-numeric codings are listed at the end of the segment field-crop description.

Field (Fd) identification number and associated crop (Cp) type.

Warner 1982-83

Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp
1	WW	2	SF	3	SW	4	SF	5	SW
6	SW	7	UK	8	UK	9	WW	10	SF
11	WW	12	WW	13	SW	14	SF	15	SW
16	SW	17	SW	18	WW	19	SF	20	WW
21	UK	22	PA	23	BY	24	SW	25	UK
26	UK	27	UK	28	UK	29	BY	30	UK
31	SF	32	SF	33	BY	34	SW	35	SF
36	SW	37	SF	38	SW	39	SF	40	SW
41	SF	42	WW	43	SF	44	WW	45	SF
46	SF	47	SW	48	WW	49	SW	50	SF
51	SW	52	SF	53	SW	54	SF	55	WW
56	SW	57	SW	58	--	59	SW	60	SW
61	UK	62	UK	63	SF	64	PA	65	SW
66	BY	67	BY	68	BY	69	PA	70	BY
71	BY	72	BY	73	BY	74	PA	75	PA
76	WW	77	SF	78	WW	79	BY	80	SW
81	--	82	BY	83	BY	84	SW	85	SF
86	UK	87	SW	88	SW	89	SW	90	SF
91	BY	92	SF	93	SW	94	SF	95	--
96	BY	97	WW	98	WW	99	SF	100	SF
101	WW	102	SF	103	SF	104	WW	105	SF
106	SW	107	SF	108	SW	109	SW	110	SF
111	SW	112	SF	113	SW	114	SF	115	BY
116	PA	117	BY	118	UK	119	SF	120	SF
121	WW	122	BY	123	SW	124	SF	125	SW
126	UK	127	UK	128	UK	129	UK	130	UK
131	UK	132	SW	133	UK	134	BY	135	SF
136	SW	137	SF	138	SW	139	--	140	--

141	--	142	--	143	--	144	WW	145	SW
146	SF	147	SW	148	SF	149	SW	150	BY
151	PA	152	UK	153	UK	154	SW	155	SF
156	SW	157	SF	158	SW	159	SF	160	WW
161	SF	162	WW	163	SF	164	SW	165	SF
166	BY	167	SF	168	SF	169	UK	170	WW
171	WW	172	SF	173	WW	174	PA	175	UK
176	SF	177	PA	178	SF	179	BY	180	SW
181	UK	182	WW	183	SF	184	SF	185	SF
186	SW	187	SF	188	UK	189	UK	190	UK
191	UK	192	UK	193	UK	194	SW	195	SF
196	SW	197	SF	198	SW	199	SF	200	WW
201	SF	202	WW	203	SF	204	WW	205	SF
206	SW	207	SF	208	WW	209	BY	210	SF
211	WW	212	UK	213	SF	214	WW	215	UK
216	WW	217	SW	218	WW	219	WW	220	SF
221	WW	222	UK	223	SW	224	SW	225	SF
226	SW	227	UK	228	SF	229	SW	230	SW
231	SW	232	SW	233	WW	234	WW	235	WW
236	UK	237	SW	238	UK	239	WW	240	SF
241	WW	242	SW	243	WW	244	SF	245	WW
246	SF	247	SF	248	WW	249	SF	250	WW
251	SF	252	SW	253	--	254	SW	255	SF
256	SW	257	SF	258	SW	259	SF	260	SW
261	SW	262	SW	263	SW	264	SF	265	SW
266	SF	267	SW	268	SF	269	SW		
15A	SF	16A	SF	243A	SW				

Field (Fd) identification number and associated crop (Cp) type.

Foremost 1982-83

Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp
1	SF	2	SF	3	--	4	SW	5	SF
6	WW	7	SW	8	SF	9	SW	10	SF
11	SW	12	SF	13	SW	14	SF	15	SW
16	SF	17	SW	18	SF	19	WW	20	WW
21	SF	22	WW	23	SF	24	SW	25	--
26	SF	27	SW	28	CN	29	SW	30	CN
31	SW	32	CN	33	SW	34	SW	35	SF
36	SW	37	SF	38	SW	39	SF	40	SW
41	SF	42	SW	43	SW	44	SW	45	SF
46	SW	47	SF	48	SF	49	SW	50	SF
51	SW	52	SF	53	WW	54	SF	55	WW
56	SW	57	SF	58	SW	59	SF	60	WW
61	SF	62	SW	63	SF	64	SW	65	SF
66	WW	67	SF	68	SW	69	SF	70	SW
71	SW	72	SF	73	SW	74	SF	75	SW
76	SF	77	SW	78	SF	79	--	80	SW
81	WW	82	SF	83	WW	84	SW	85	SF

86	SW	87	SF	88	--	89	SW	90	SF
91	SW	92	SF	93	WW	94	SF	95	WW
96	SF	97	SF	98	SW	99	SF	100	WW
101	SF	102	SW	103	SF	104	UK	105	SF
106	SW	107	SF	108	--	109	SW	110	SF
111	FL	112	SF	113	--	114	SW	115	SW
116	SF	117	SW	118	SF	119	SW	120	SF
121	BY	122	WW	123	SF	124	WW	125	SF
126	WW	127	SF	128	WW	129	BY	130	SF
131	SW	132	SF	133	--	134	--	135	--
136	--	137	--	138	--	139	--	140	--
141	SW	142	SF	143	SW	144	SF	145	WW
146	WW	147	SF	148	SF	149	SW	150	SF
151	SW	152	SW	153	--	154	SF	155	SW
156	SF	157	--	158	SF	159	SW	160	SW
161	SF	162	SW	163	SF	164	BY	165	--
166	--	167	--	168	WW	169	SF	170	WW
171	SF	172	WW	173	SF	174	SW	175	BY
176	SW	177	SF	178	SW	179	SF	180	SW
181	SF	182	SW	183	SW	184	SF	185	SW
186	--	187	--	188	UK	189	UK	190	WW
191	SF	192	WW	193	SF	194	WW	195	SF
196	WW	197	SF	198	WW	199	OT	200	SF
201	SW	202	SF	203	SW	204	SF	205	SW
206	SF	207	SW	208	PA	209	PA	210	CN
211	PA	212	PA	213	PA	214	PA	215	PA
216	UK	217	OT	218	SW				

Field (Fd) identification number and associated crop (Cp) type.

Skiff 1982-83

Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp
1	SF	2	SW	3	SF	4	WW	5	SF
6	WW	7	SF	8	WW	9	UK	10	WW
11	UK	12	WW	13	UK	14	WW	15	UK
16	WW	17	PA	18	WW	19	SF	20	SF
21	OT	22	SF	23	SW	24	WG	25	SW
26	SW	27	SF	28	SW	29	WW	30	SF
31	SW	32	SF	33	SW	34	SF	35	WW
36	UK	37	WW	38	PA	39	PA	40	UK
41	SW	42	SF	43	SW	44	SF	45	SW
46	--	47	--	48	--	49	--	50	SF
51	WW	52	UK	53	WW	54	UK	55	PA
56	PA	57	SW	58	SF	59	SW	60	SF
61	--	62	--	63	--	64	--	65	--
66	--	67	--	68	WW	69	SF	70	WW
71	SF	72	WW	73	SF	74	WW	75	SF
76	SF	77	SW	78	SF	79	SW	80	SF

81	SW	82	SF	83	SW	84	PA	85	SW
86	SF	87	SW	88	PA	89	SF	90	SW
91	SF	92	SW	93	SF	94	SW	95	SF
96	BY	97	SF	98	SW	99	SF	100	SW
101	SF	102	SW	103	SF	104	SW	105	SF
106	SW	107	SF	108	SW	109	SF	110	SW
111	SF	112	SW	113	CN	114	SF	115	WW
116	WW	117	PA	118	SW	119	SF	120	SW
121	SF	122	SW	123	SF	124	SW	125	SF
126	SF	127	WW	128	SF	129	BY	130	PA
131	BY	132	SW	133	SW	134	SF	135	SW
136	SF	137	SW	138	SF	139	SW	140	SF
141	SW	142	SF	143	WW	144	SF	145	SW
146	SF	147	SW	148	SW	149	BY	150	SF
151	UK	152	OT	153	SF	154	PA	155	PA
156	SW	157	SF	158	SW	159	SF	160	SW
161	SF	162	SW	163	SF	164	SW	165	SF
166	SW	167	SF	168	SW	169	SF	170	SF
171	SW	172	SF	173	SW	174	SF	175	SW
176	SF	177	SW	178	UK	179	SF	180	SF
181	SW	182	SF	183	SW	184	SF	185	SW
186	SW	187	SF	188	SW	189	SF	190	SW
191	SF	192	SW	193	SF	194	SW	195	SF
196	SW	197	SF	198	SW	199	SF	200	SW
201	SF	202	--	203	SF	204	BY	205	SF
206	BY	207	SF	208	SW	209	SF	210	SW
211	SW	212	PA	213	SF	214	BY	215	SF
216	BY	217	SF	218	SW	219	SF	220	SW
221	SF	222	BY	223	SF	224	BY	225	SF
226	SW	227	SF	228	BY	229	SF	230	SW
231	BY	232	WW	233	SW	234	SF	235	SW
236	SF	237	WW	238	SF	239	WW	240	SF
241	PA	242	SF	243	SW	244	SF	245	SF
246	WW	247	SF	248	SW	249	SF	250	WW
251	SW	252	--	253	--	254	--	255	--
256	--	257	--	258	--	259	--	260	SW
261	SF	262	SW	263	SF	264	WW	265	SF
266	WW	267	SF	268	SF	269	SW	270	SF
271	SW	272	SF	273	SW	274	SF	275	OT
276	SF	277	SW	278	SW	279	SF	280	SW
281	SF	282	SW	283	SF	284	SW	285	SF
286	SW	287	SF	288	SW	289	SF	290	--
291	--	292		293	--	294	--	295	--
296	--	297	--	298	--	299	--	300	SF
301	SW	302	SW	303	SF	304	SW	305	SF
306	SW	307	SW	308	SF	309	SW	310	SF
311	SW	312	SF	313	SW	314	SF	315	SW
316	SF	317	SW	318	SF	319	SW	320	SF
321	WW	322	WW	323	WW				

Field (Fd) identification number and associated crop (Cp) type.

Foremost 1983-84

Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp
1	SW	2	BY	3	SW	4	SW	5	CN
6	SF	7	SW	8	UK	9	UK	10	SW
11	SF	12	SW	13	SF	14	SW	15	SF
16	SW	17	SF	18	WW	19	SF	20	SF
21	WW	22	SF	23	WW	24	SF	25	SW
26	SW	27	SW	28	SW	29	SW	30	SW
31	SW	32	SW	33	SW	34	SF	35	SW
36	SF	37	SW	38	SF	39	SW	40	SF
41	SW	42	UK	43	UK	44	SF	45	WW
46	SF	47	WW	48	WW	49	SF	50	WW
51	SF	52	WW	53	SF	54	WW	55	SF
56	SF	57	SW	58	SF	59	SW	60	SF
61	SW	62	SF	63	CN	64	SF	65	WW
66	SF	67	WW	68	SF	69	WW	70	SF
71	SF	72	WW	73	SF	74	WW	75	SF
76	SW	77	SF	78	SW	79	SF	80	SF
81	SW	82	SW	83	SF	84	SF	85	SW
86	SF	87	SW	88	SF	89	SF	90	WW
91	SF	92	WW	93	SF	94	WW	95	SF
96	WW	97	SW	98	SF	99	WW	100	SF
101	SW	102	SF	103	SW	104	UK	105	BY
106	SF	107	BY	108	--	109	SF	110	--
111	FL	112	--	113	--	114	SW	115	SF
116	SW	117	SF	118	SW	119	SF	120	WW
121	SF	122	SF	123	WW	124	SF	125	SW
126	SF	127	WW	128	SF	129	WW	130	SF
131	SF	132	SW	133	SF	134	SW	135	--
136	--	137	--	138	--	139	--	140	SW
141	SF	142	SW	143	SF	144	SW	145	SF
146	SF	147	SW	148	SW	149	SF	150	SW
151	SF	152	SW	153	--	154	SW	155	SF
156	SW	157	--	158	SW	159	SF	160	SF
161	WW	162	SF	163	SW	164	BY	165	SF
166	BY	167	SF	168	SF	169	WW	170	SF
171	WW	172	SF	173	WW	174	SF	175	SF
176	SW	177	WW	178	SF	179	SW	180	SF
181	SW	182	SF	183	UK	184	WW	185	UK
186	--	187	--	188	UK	189	UK	190	UK
191	WW	192	SF	193	WW	194	SF	195	CN
196	SF	197	SW	198	SF	199	UK	200	WW
201	SF	202	WW	203	SF	204	WW	205	SF
206	SW	207	SF	208	CN	209	SF	210	WW
211	PA	212	PA	213	PA	214	PA	215	PA
216	SF								
1A	SW	131A	SW	131B	SF	131C	SF	210A	SF

Field (Fd) identification number and associated crop (Cp) type.

Taber 1983-84

Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp
1	SW	2	--	3	--	4	PS	5	SW
6	UK	7	PS	8	SW	9	BY	10	CN
11	UK	12	UK	13	UK	14	SW	15	--
16	FG	17	BY	18	SW	19	--	20	FG
21	SB	22	FG	23	UK	24	--	25	UK
26	--	27	UK	28	--	29	SW	30	--
31	SW	32	SB	33	FG	34	UK	35	UK
36	UK	37	SB	38	SW	39	FG	40	SB
41	SB	42	CO	43	SW	44	FG	45	CO
46	FG	47	--	48	--	49	UK	50	UK
51	UK	52	UK	53	UK	54	FG	55	SB
56	FG	57	FG	58	SW	59	BY	60	SW
61	BY	62	SW	63	UK	64	UK	65	UK
66	BY	67	FG	68	--	69	SW	70	SW
71	SW	72	BY	73	FG	74	SW	75	SW
76	CN	77	SW	78	SW	79	BY	80	--
81	--	82	PS	83	SW	84	--	85	SW
86	--	87	--	88	--	89	--	90	--
91	--	92	--	93	--	94	--	95	SB
96	--	97	--	98	--	99	--	100	PT
101	SW	102	BY	103	SW	104	SW	105	BY
106	PT	107	FG	108	BY	109	SW	110	SF
111	SW	112	SF	113	SW	114	SF	115	SW
116	PT	117	SW	118	PS	119	FG	120	SW
121	SW	122	SW	123	PS	124	PS	125	SB
126	SF	127	SW	128	SW	129	SF	130	SW
131	SF	132	SW	133	SF	134	SW	135	SF
136	SW	137	SF	138	SW	139	SF	140	SW
141	SB	142	SW	143	BY	144	SW	145	SW
146	PS	147	SB	148	FG	149	FG	150	SF
151	SW	152	SF	153	SW	154	SF	155	SW
156	SF	157	SW	158	--	159	--	160	SW
161	--	162	--	163	--	164	--	165	--
166	FG	167	SW	168	FG	169	BY	170	SW
171	SW	172	SW	173	FG	174	--	175	BY
176	SW	177	--	178	--	179	FG	180	FG
181	BY	182	--	183	--	184	--	185	--
186	FG	187	--	188	FG	189	FG	190	SW
191	--	192	SW	193	SW	194	CN	195	UK
196	FG	197	SB	198	--	199	CN	200	FG
201	--	202	CN	203	--	204	--	205	FG
206	--	207	--	208	--	209	--	210	BY
211	SF	212	SW	213	SF	214	SW	215	SF
216	SW	217	SF	218	SF	219	SW	220	SF
221	SW	222	--	223	WW	224	SF	225	WW

226	SF	227	BY	228	SF	229	BY	230	SF
231	--	232	SW	233	SF	234	SW	235	--
236	SW	237	SB	238	SW	239	--	240	--
241	--	242	--	243	--	244	SW	245	--
246	PS	247	--	248	SB	249	--	250	SW
251	--	252	SW	253	SF	254	SW	255	SF
256	SW	257	SW	258	SF	259	SW	260	SF
261	SW	262	CN	263	PS	264	WW	265	SB
266	SW	267	--	268	--	269	SF	270	WW
271	SF	272	WW	273	SF	274	SF	275	SW
276	SW	277	SF	278	SW	279	SW	280	SF
281	WW	282	SF	283	WW	284	SF	285	WW
286	WW	287	SW	288	WW	289	WW	290	SF
291	WW	292	FG	293	SF	294	FG	295	SF
296	WW	297	SF	298	WW	299	SF	300	WW
301	SF	302	--	303	--	304	WW	305	UK
306	UK	307	UK	308	UK	309	SF	310	SW
311	SF	312	--	313	--	314	--	315	--
316	--	317	SW	318	--	319	--	320	--
321	--	322	--	323	SW	324	CN	325	SF
326	WW	327	SF	328	BY	329	SF	330	BY
331	SF	332	WW	333	--	334	SF	335	SW
336	SF	337	SW	338	SF	339	CN	340	WW
341	SF	342	BY	343	CN	344	BY	345	CN
346	UK	347	--	348	SW	349	SF	350	SF
351	--	352	SW	353	--	354	SF	356	--
356	WW	357	--	358	SF	359	--	360	WW
361	--	362	--	363	SF	364	WW	365	--
366	SF	367	--	368	WW	369	SF	370	WW
371	SF	372	WW	373	SF	374	CN	375	BY
376	SF	377	SF	378	SW	379	SF	380	SW
381	SF	382	SW	383	SF	384	--	385	SW
386	SF	387	SW	388	SF	389	SW	390	SF
391	WW	392	SF	393	WW	394	SW	395	SF
396	SW	397	SF	398	SW	399	SF	400	SW
401	SF	402	SW	403	SF	404	SW	405	CN
406	SF	407	SF	408	SF	409	UK	410	SF
411	--	412	--	413	--	414	SF	415	--
416	SW	417	--	418	FG	419	--	420	SW
421	--	422	FG	423	SF	424	CN	425	SF
426	SW	427	SF	428	SW	429	SF	430	By
431	SW	432	SF	433	SW	434	SF	435	SW
436	SF	437	WW	438	SF	439	SF	440	SW
441	SF	442	SW	443	SF	444	SW	445	SF
446	SW	447	CN	448	--	449	SF	450	CN
451	SF	452	--	453	CN	454	SF	455	SW
456	SW	457	CN	458	SF				

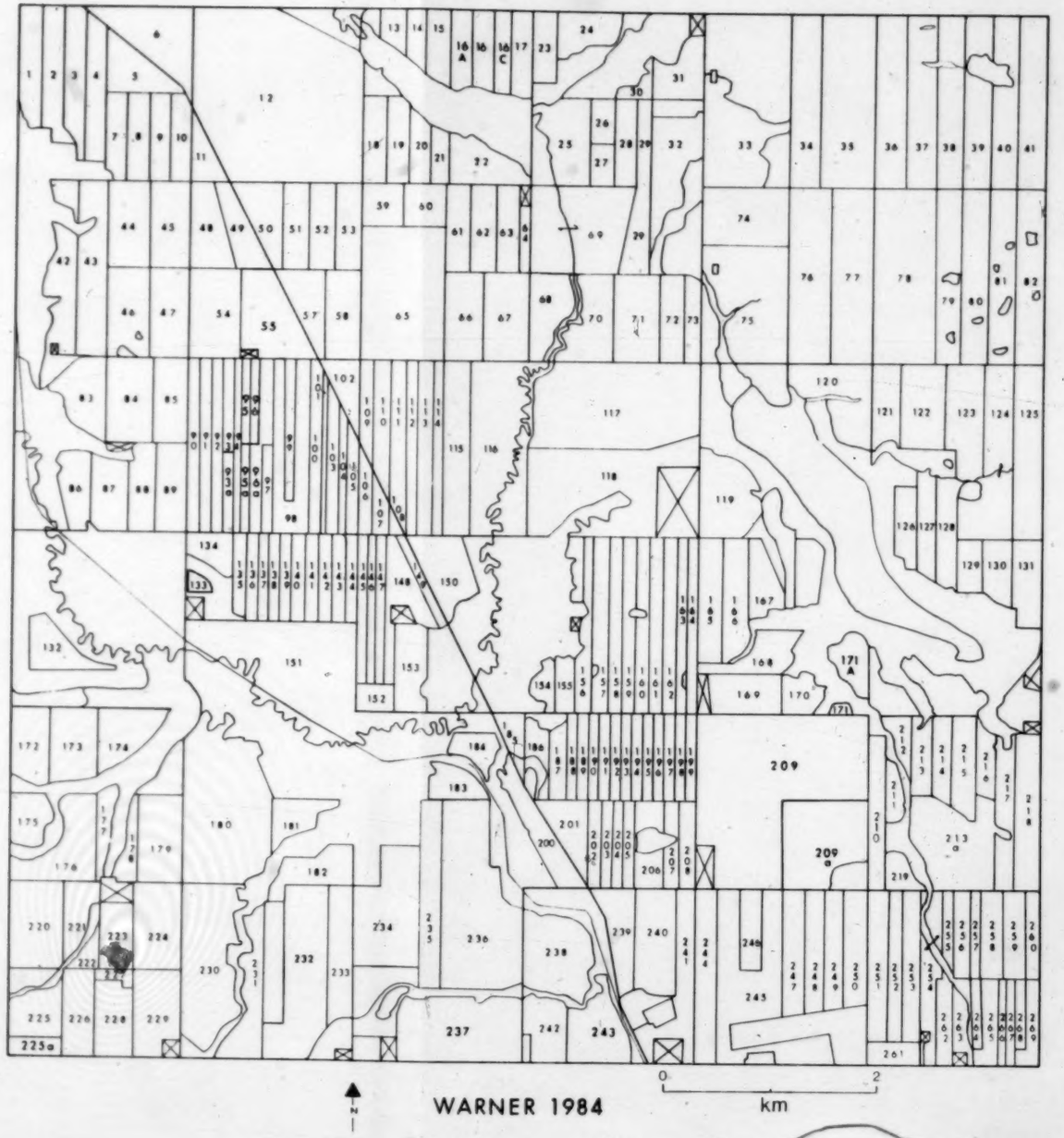
127a	SF	278a	SF	400a	FG	401a	UK	402a	UK
403a	UK	404a	UK	405a	UK	406a	SW		

Field (Fd) identification numeric and associated crop (Cp) type.

Warner 1983-84

Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp	Fd	Cp
1	SF	2	SW	3	SF	4	SW	5	SW
6	SW	7	SW	8	SF	9	SW	10	SW
11	SW	12	SW	13	SF	14	SW	15	SF
16	SF	17	SW	18	SF	19	WW	20	SF
21	WW	22	PA	23	SF	24	SF	25	UK
26	UK	27	UK	28	UK	29	UK	30	UK
31	UK	32	UK	33	SF	34	SF	35	WW
36	SF	37	SW	38	SF	39	SW	40	SF
41	SW	42	SF	43	WW	44	SF	45	WW
46	CN	47	SF	48	SW	49	SF	50	SW
51	SF	52	SW	53	SW	54	WW	55	--
56	SW	57	UK	58	SF	59	SF	60	SW
61	WW	62	SF	63	WW	64	PA	65	BY
66	SW	67	SW	68	SW	69	PA	70	SW
71	SW	72	SW	73	SW	74	UK	75	PA
76	SW	77	WW	78	SW	79	SF	80	SW/
81	SW	82	SF	83	SF	84	BY	85	SW
86	WW	87	SF	88	SW	89	SW	90	SW
91	SF	92	BY	93	SF	94	SW	95	SW
96	SW	97	UK	98	SF	99	WW	100	WW
101	SF	102	BY	103	WW	104	SF	105	WW
106	SF	107	WW	108	SF	109	SW	110	WW
111	SW	112	WW	113	SW	114	WW	115	BY
116	PA	117	SF	118	UK	119	SW	120	WW
121	SF	122	BY	123	SF	124	WW	125	SF
126	SF	127	WW	128	SF	129	WW	130	SF
131	WW	132	SW	133	PA	134	SF	135	SW
136	SW	137	SW	138	SW	139	SF	140	SW
141	SF	142	SW	143	SF	144	SW	145	SF
146	SW	147	SF	148	SW	149	UK	150	UK
151	UK	152	UK	153	UK	154	SF	155	WW
156	SF	157	SW	158	SF	159	SW	160	SF
161	WW	162	SF	163	SW	164	SF	165	SW
166	SF	167	SW	168	UK	169	WW	170	SF
171	SF	172	WW	173	UK	174	PA	175	SW
176	WW	177	PA	178	SF	179	BY	180	SW
181	UK	182	UK	183	UK	184	WW	185	WW
186	SF	187	WW	188	SF	189	WW	190	SF
191	WW	192	SF	193	WW	194	SF	195	WW
196	SF	197	WW	198	SF	199	WW	200	SF
201	SW	202	SF	203	SW	204	SF	205	SW
206	BY	207	SW	208	SF	209	BY	210	WW
211	SF	212	SF	213	WW	214	SF	215	WW
216	SF	217	WW	218	SF	219	SF	220	SW
221	SW	222	SW	223	BY	224	SF	225	WW

226	SF	227	UK	228	WW	229	CN	230	SW
231	SW	232	SW	233	SW	234	SW	235	SW
236	SW	237	SW	238	SW	239	SF	240	WW
241	SF	242	SW	243	SW	244	WW	245	SF
246	WW	247	WW	248	SF	249	WW	250	SF
251	SW	252	SF	253	SW	254	UK	255	UK
256	UK	257	UK	258	UK	259	SW	260	UK
261	UK	262	UK	263	UK	264	WW	265	BY
266	WW	267	BY	268	WW	269	SF		
16A	CN	16C	CN	93A	SF	95A	WW	171A	UK
209A	CN	213A	SW						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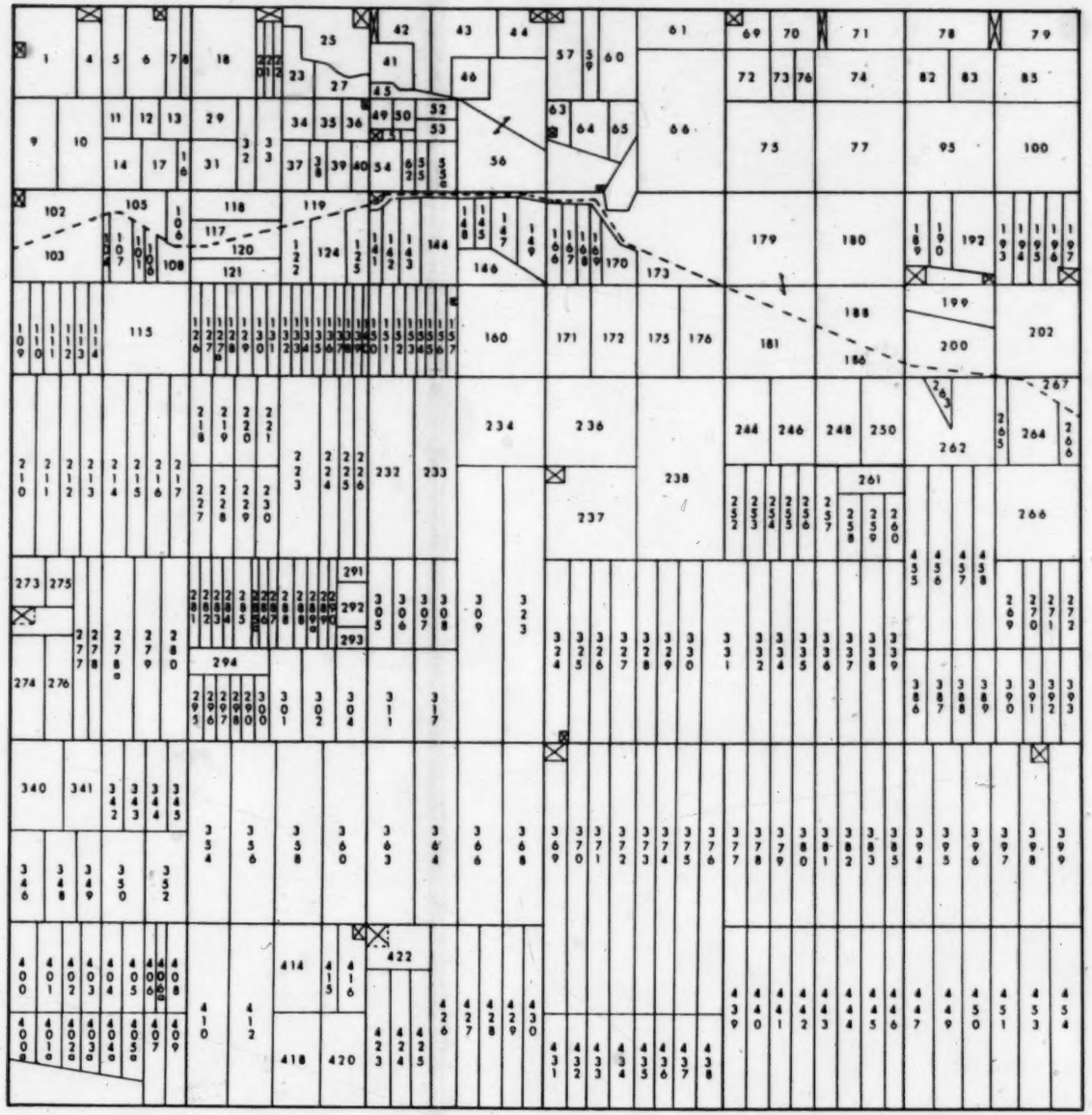
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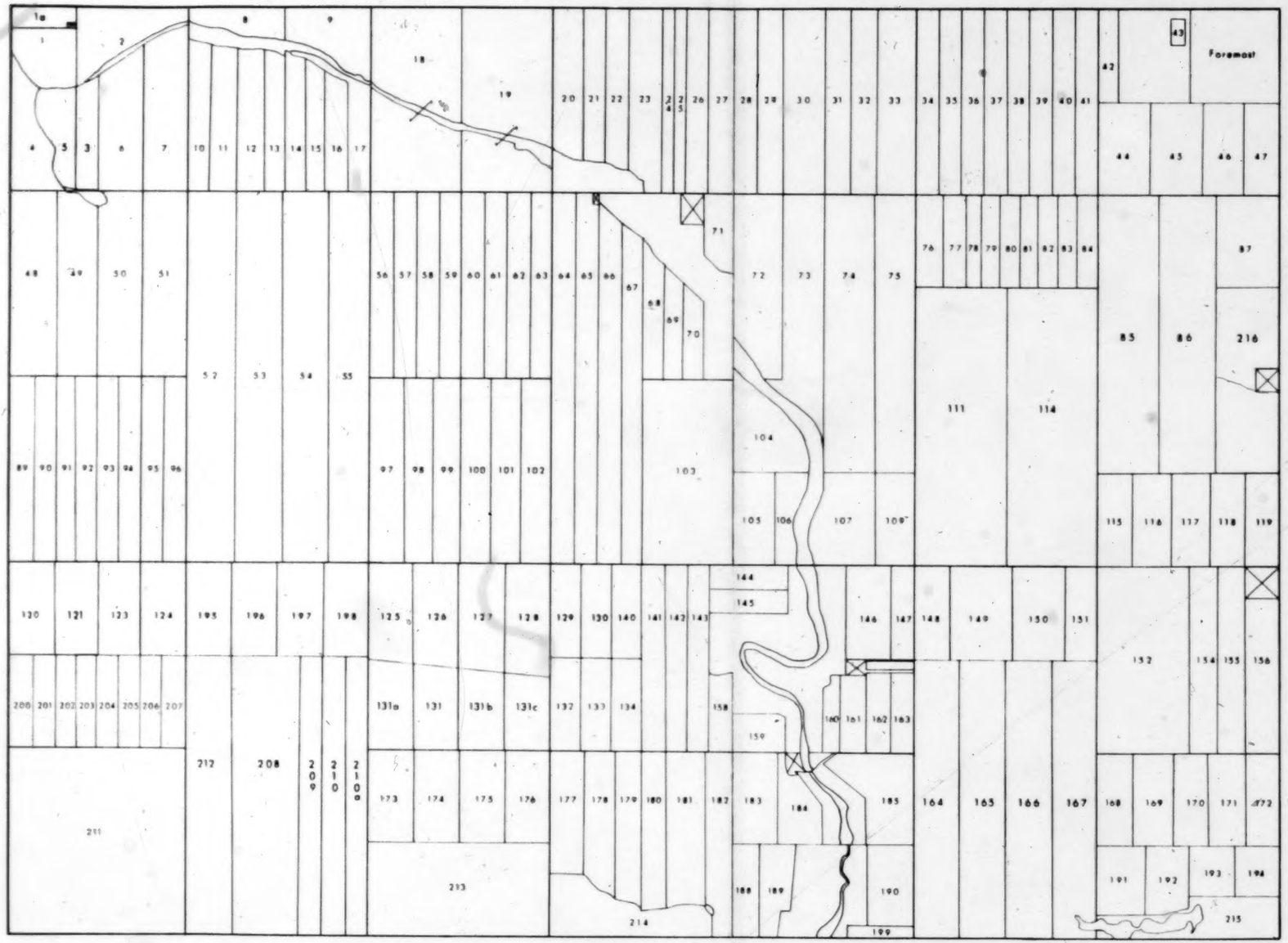
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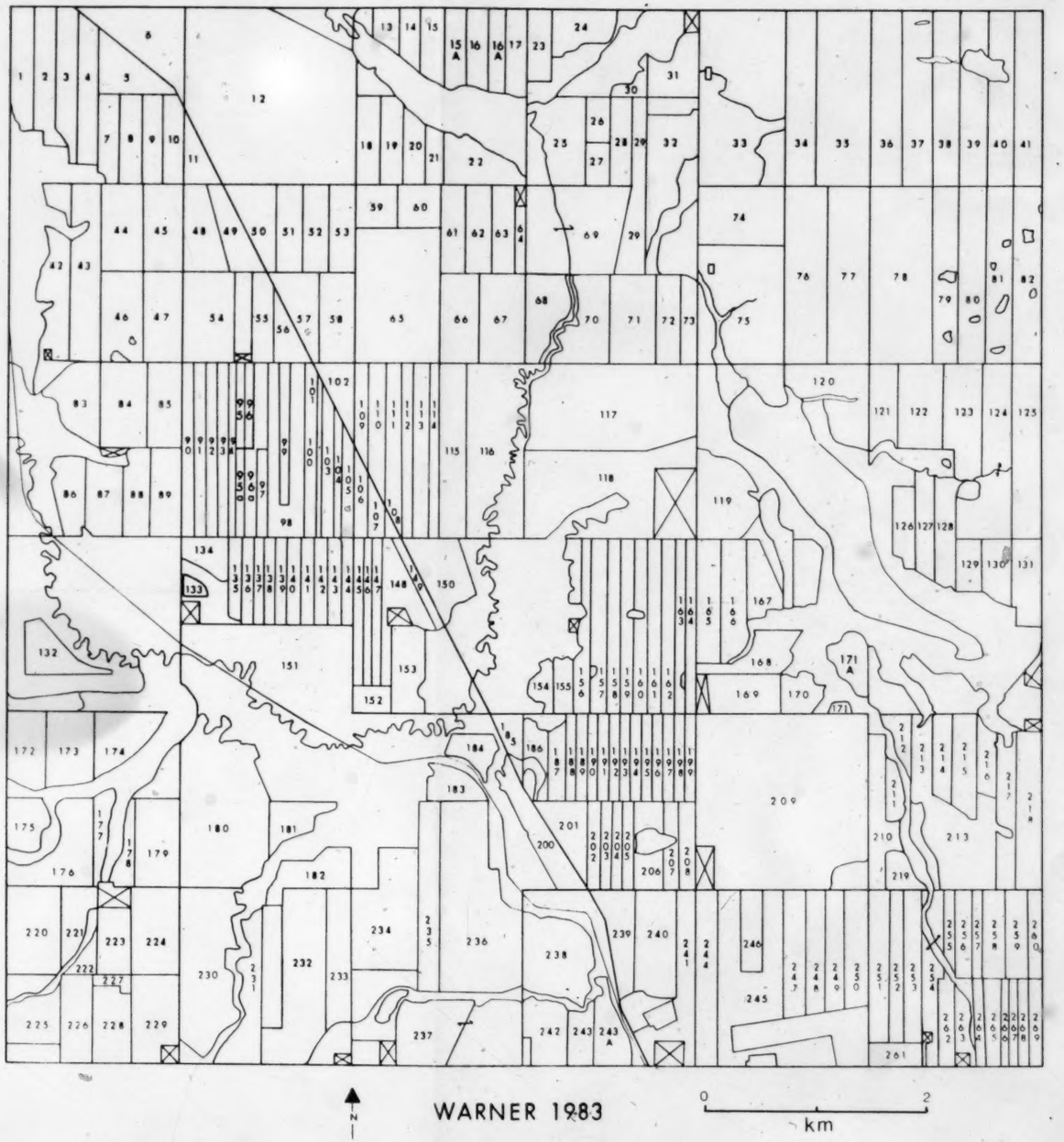
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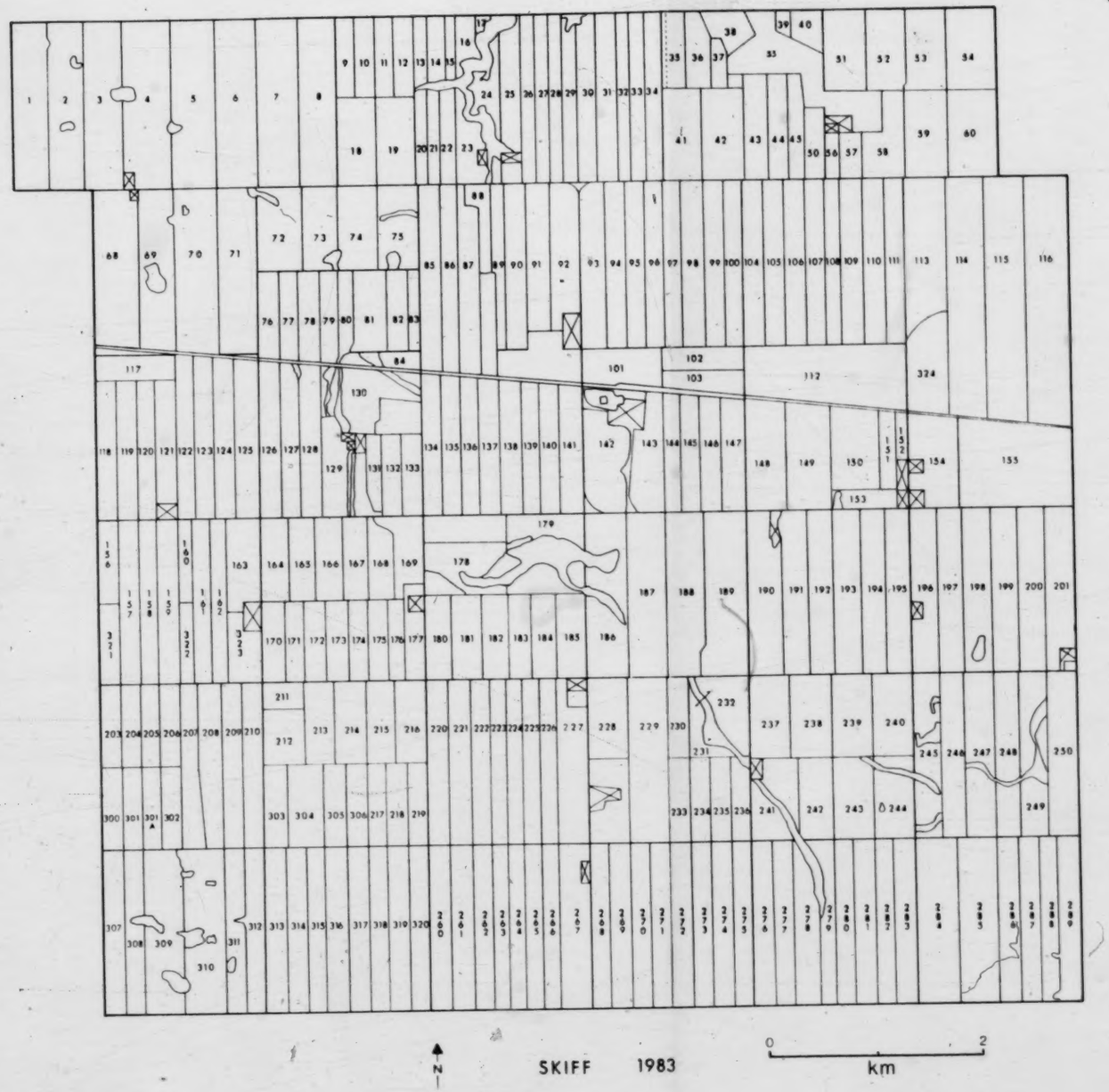

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SKIFF 1983

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FOREMOST 1983